Future Directions in Ionospheric Space Weather Applications

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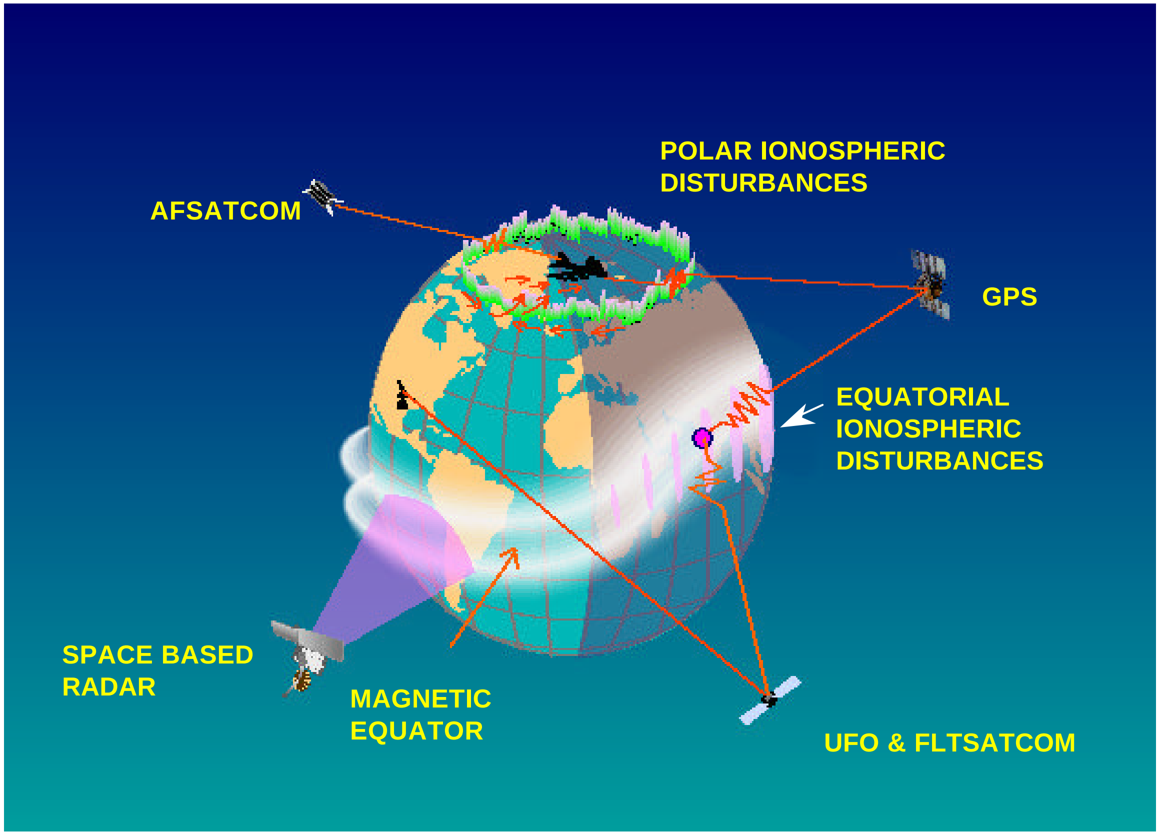
Introduction

- Space Weather
  Ionospheric effects impact:
  - Communications
  - Navigation
  - Surveillance systems
- Maximum impact at:
  - High latitudes
  - Low latitudes



Applications to improve the performance of Nav, Com & Surv Systems through Real Time Global Monitoring, Specification and Forecast of Ionospheric Hazards

Main Challenges in Applied Ionospheric Physics

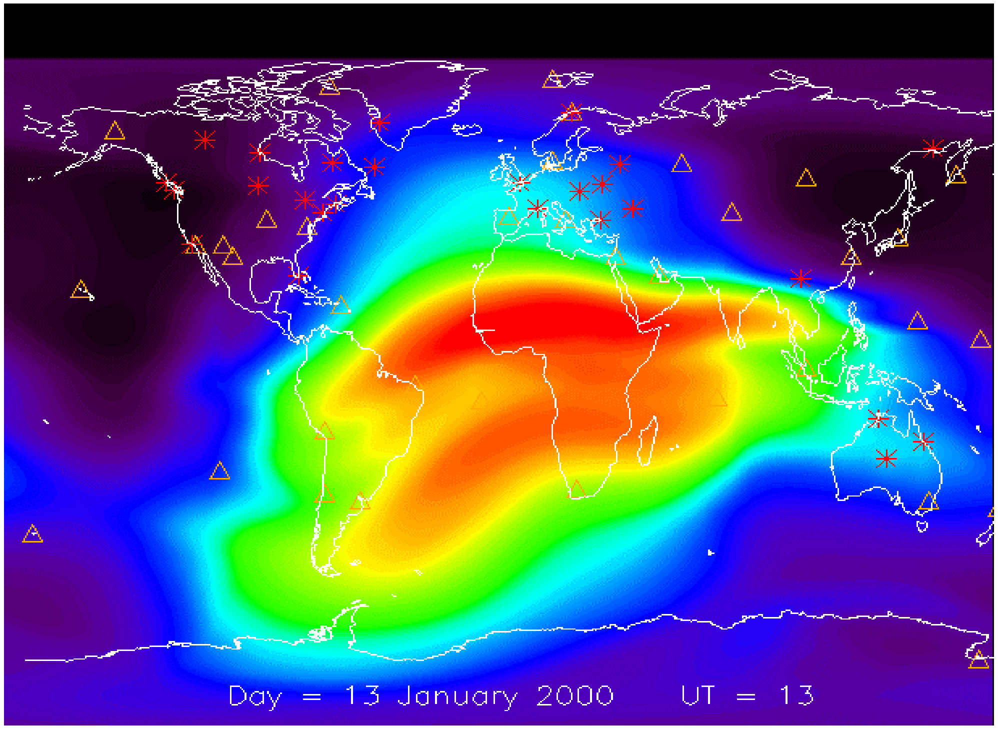
OUTLINE

1. Assimilate large and disparate data sets
2. Forecast far into the future
3. Couple and link models together
4. Make the right measurement
5. Establish how systems are affected—build products
6. Validate and benchmark models and products
7. Transition products / implement solutions

CONCLUSIONS

Assimilation Models

- **Ionospheric models**
  - **PRISM (Parameterized Real-time Ionosphere Model) DoD operational model**
  - **CITEFM (Coupled Ionospheric Thermospheric Electrodynamic Forecast Model)**
  - **MURI (GAIM)**
  - **Other**
- **Challenges:**
  - **Large and disparate data to assimilate**
    - **Model drivers (E, wind)**
    - **Integrated quantities (TEC, Radiance)**
    - **Multiple sensors**
  - **What 'sub-models' to include**



TEC output from PRISM, driven with GPS data

Forecast

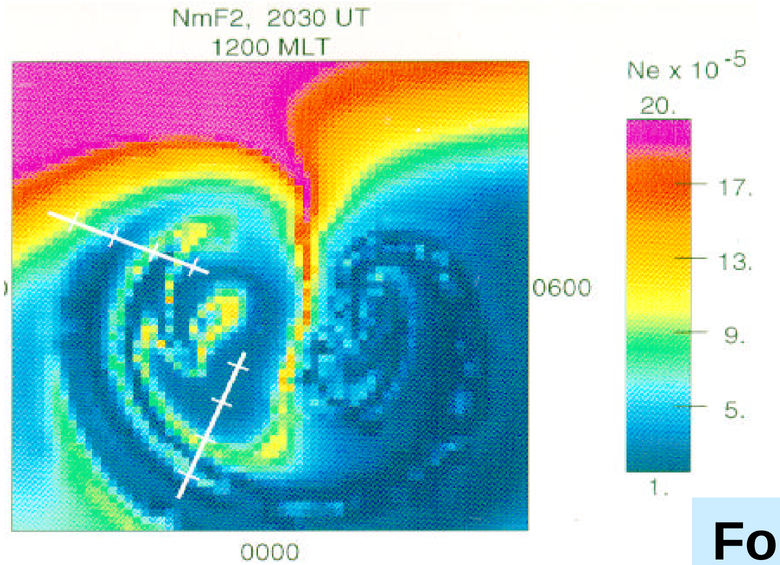
Need accurate physics based model

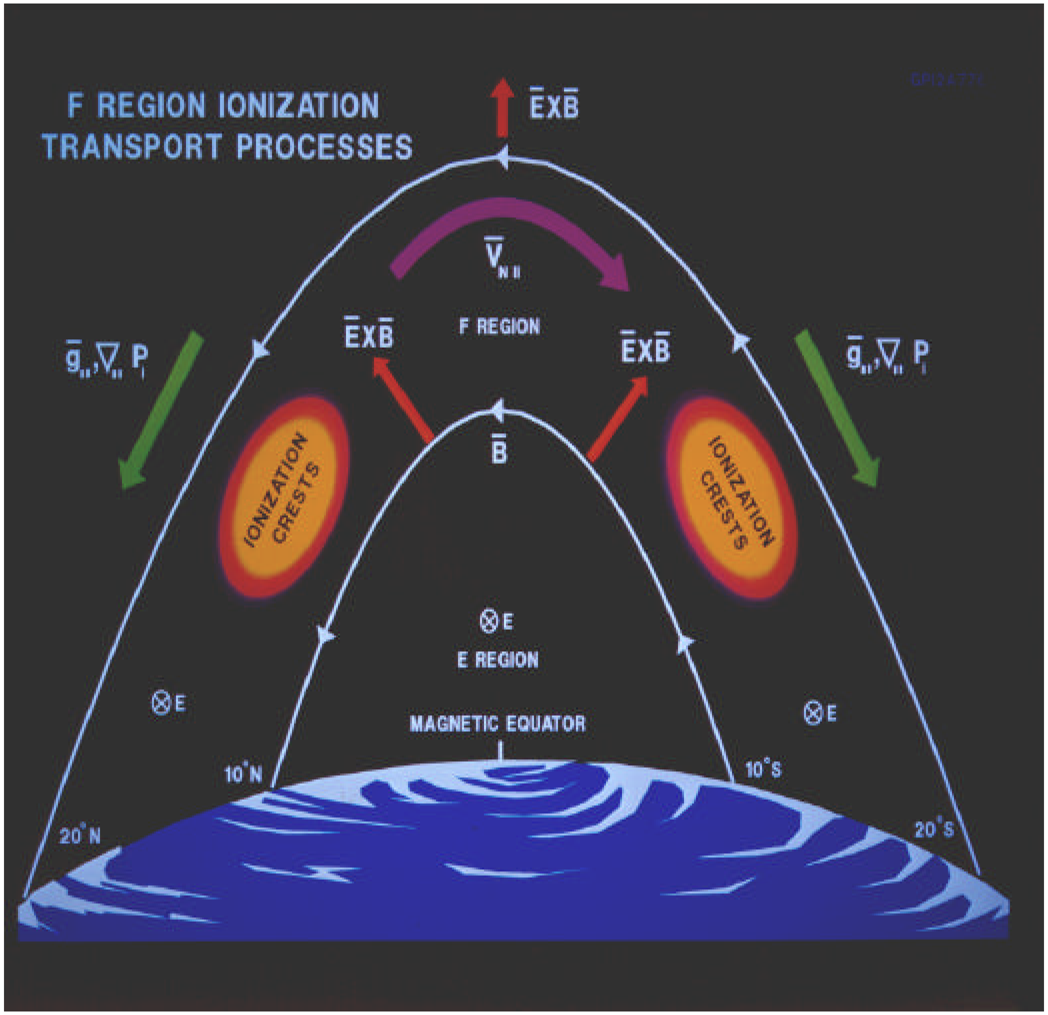
Need accurate empirical models as part of physics based model

Need accurate forecast of drivers

Examples:

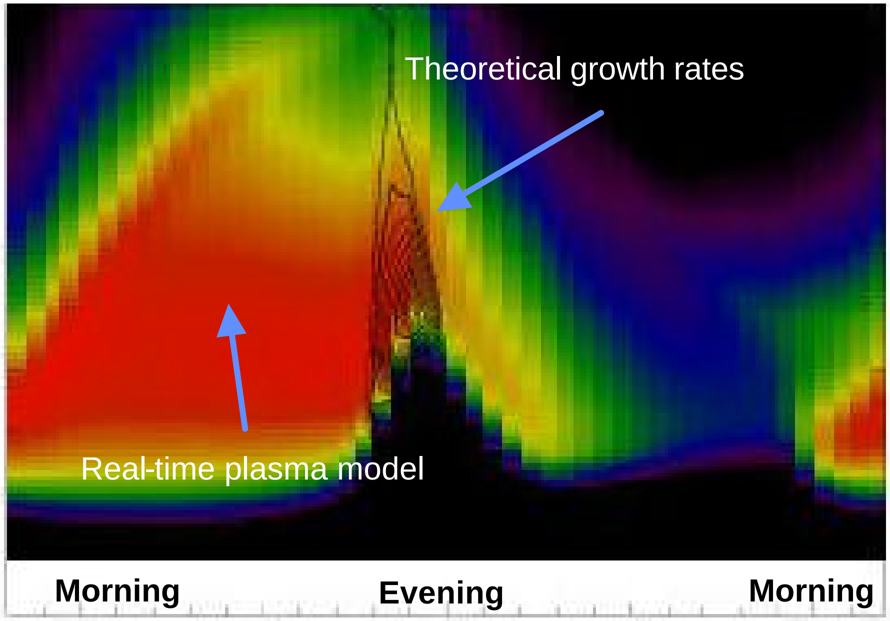
- High lat physical model
- Low lat model used for C/NOFS

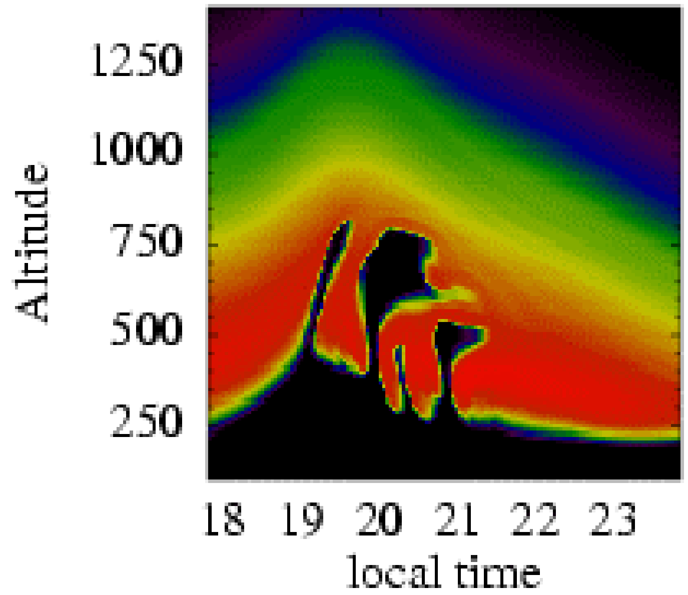




Forecasts: >6 hr required for some applications

Couple and Link Models

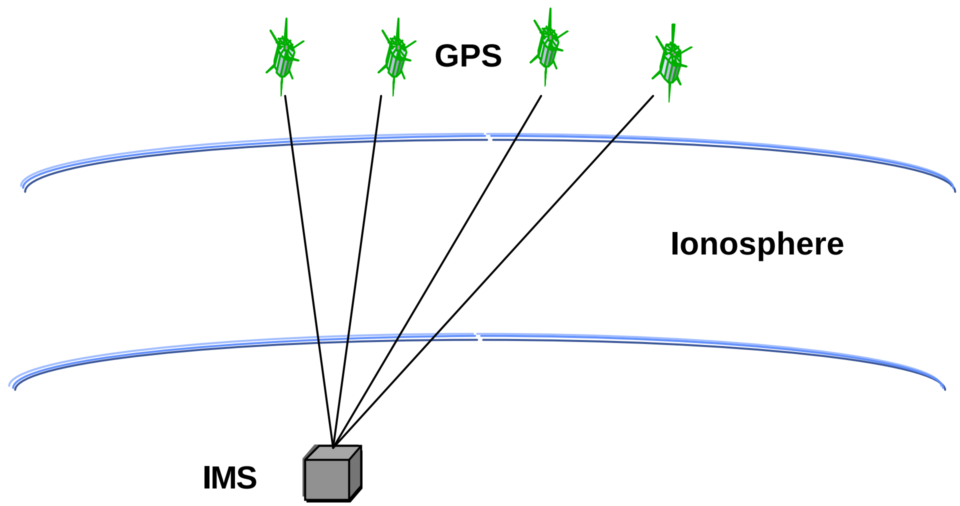


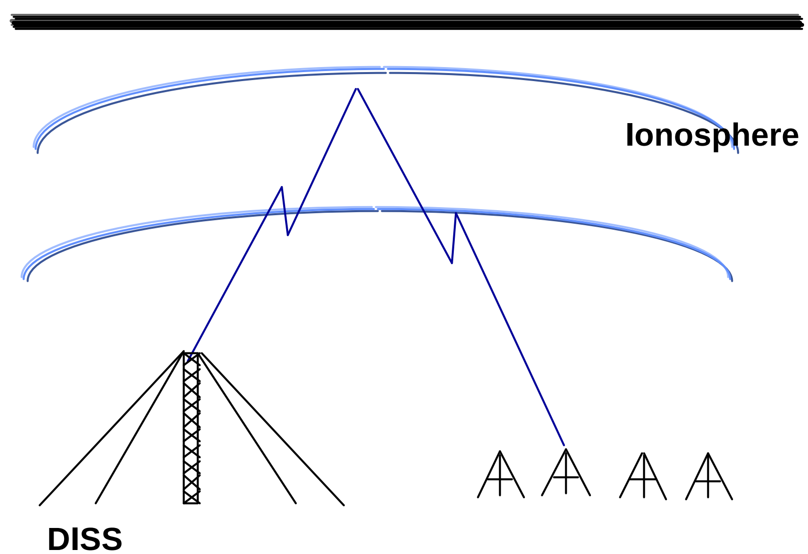


- **Equatorial ionosphere illustration**
  - **Coupled Ionosphere-thermosphere forecast model (will assimilate real-time data)**
  - **Linked to theoretical growth-rate model (left)**
  - **Linked to non-linear plasma bubble evolution (right)**

Ground Based Measurements

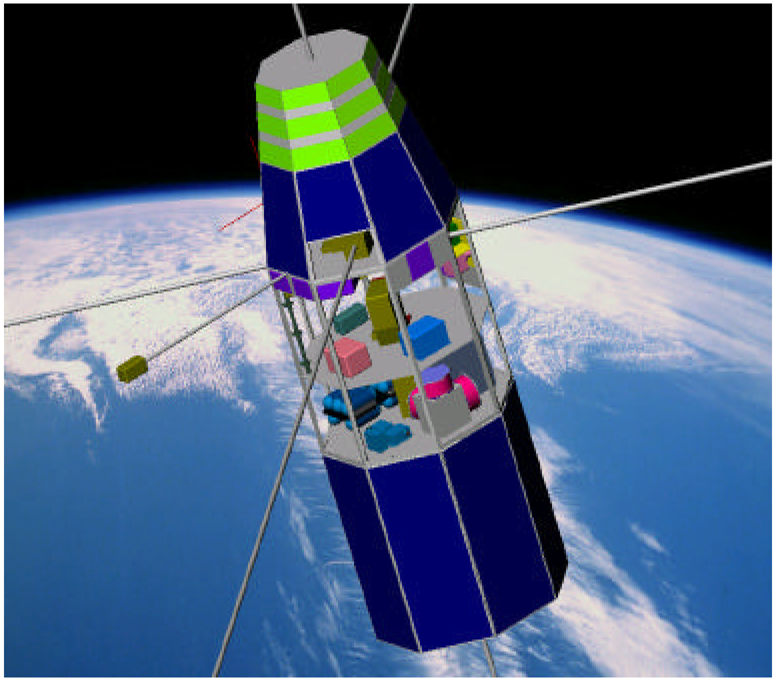
- Operational ground based sensors
  - GPS receivers (IMS)
  - Scintillation receivers (SCINDA)
  - Ionosondes (DISS)
  - magnetometers
- Other Possible Sensors
  - Radars
  - Imagers
- Future challenges
  - Operational systems are reliable, accurate, thus expensive
  - Small, cheap, abundant sensors





Satellite Measurements

- **C/NOFS: equatorial satellite 400-700 km orbit (2003 launch)**
- **Next Generation Technologies:**
  - **DMSP (new UV and particle detectors)**
  - **NPOESS (2008 and beyond)**
- **Living With a Star Ionospheric Mappers (includes C/NOFS)**

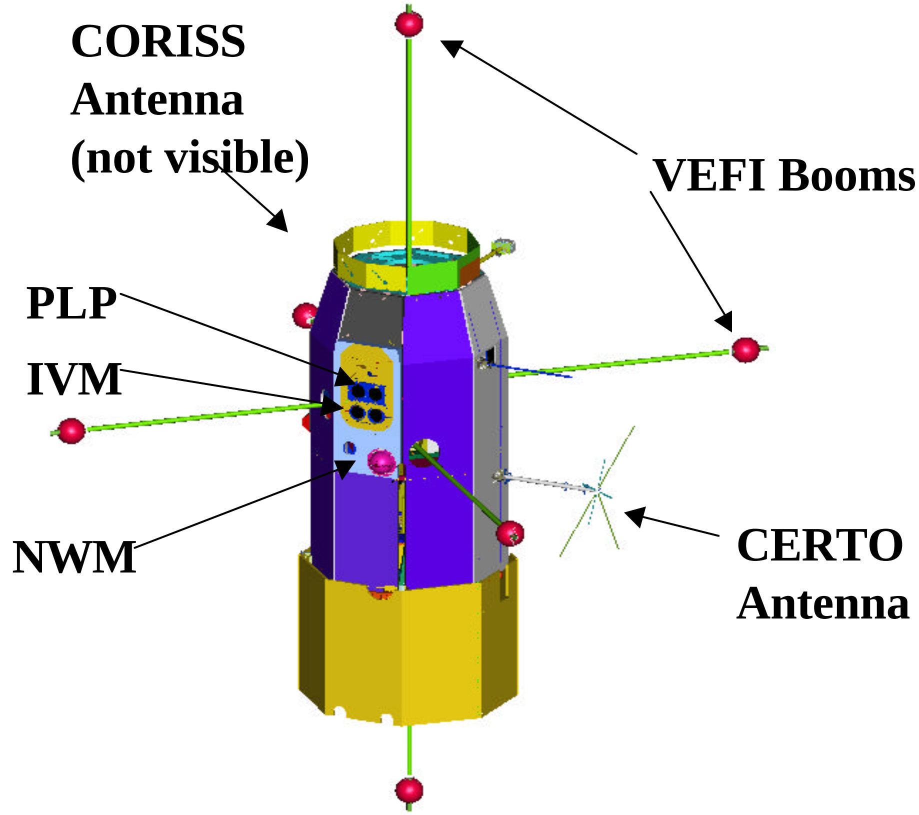


Communications/Navigation Outage Forecast System

C/NOFS PROGRAM

C/NOFS satellite mission: provide 4-6 hr scintillation forecast

- **Instruments will measure:**
  - **Electric and Magnetic fields**
  - **Plasma density, temperatures**
  - **Neutral wind**
  - **Density (GPS occultation)**
  - **scintillation (Radio Beacon)**
  - **scintillation and TEC (Ground based receivers)**
- **Multi-agency project**
- **Plan to instigate program for Guest Investigators / ground-based instruments**



C/NOFS Instruments Payload

Plasmas and Fields Measurements

PLP	Planar Langmuir Probe	AFRL	Dr. D. Hunton
VEFI	Vector Electric Field Instr	NASA/GSFC	Dr. R. Pfaff
IVM	Ion Velocity Meter	UTD (NASA sponsored)	Dr. R. Heelis

Neutral Atmosphere Measurements

NWM	Neutral Wind Meter	UTD (NASA sponsored)	Dr. R. Heelis

Electron Content Measurements

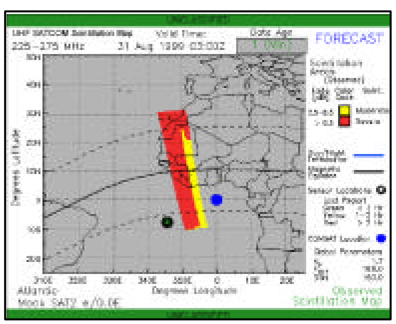
CORISS	GPS Occultation Receiver	Aerospace Corp (NPOESS sponsored)	Dr. P. Straus

Scintillation Measurements

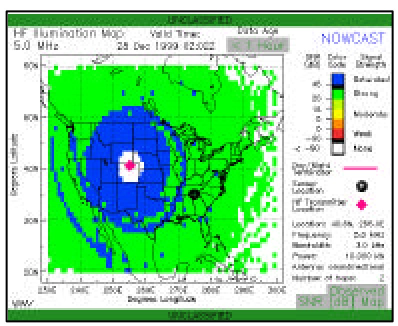
CERTO	RF Radio Beacon	NRL	Dr. P. Bernhardt

Operational Space Environment Network Display (OpSEND)

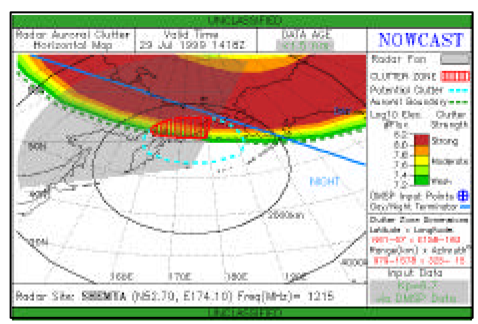
- **Models are tools used to generate end-user applications,**
- **OpSEND incorporates state-of-the-art sensors, models, and display tools to generate Space Weather impact maps** (Bishop et al., 2000) **:**
  - **UHF SATCOM Scintillation Map** (Groves et al.)
  - **HF Illumination Map** (Bullett et al.)
  - **Auroral Clutter Boundary Map** (Quigley et al.)
  - **Estimated GPS Single-Frequency Error Map** (Bishop et al.)



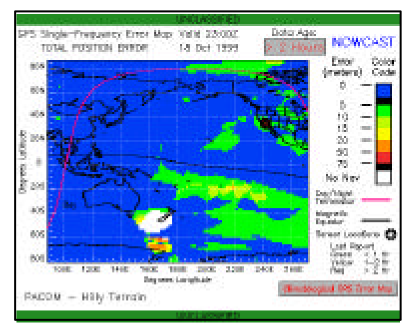
UHF SATCOM Scintillation Map



HF Illumination Map



Auroral Clutter Boundary Map

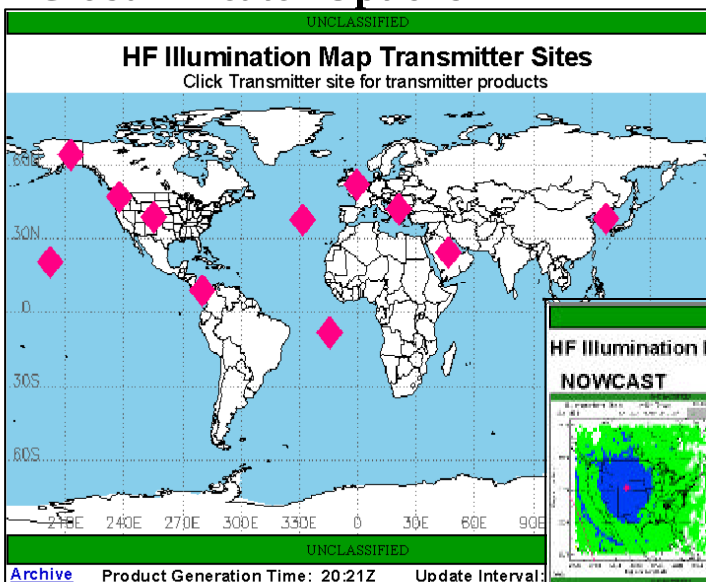


Estimated GPS Single-Frequency Error Map

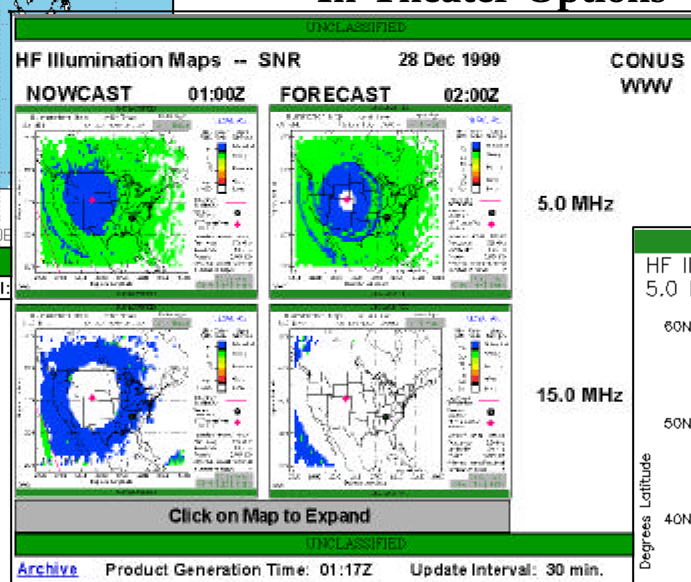
OpSEND HF Illumination Map

3 - Level Web Page

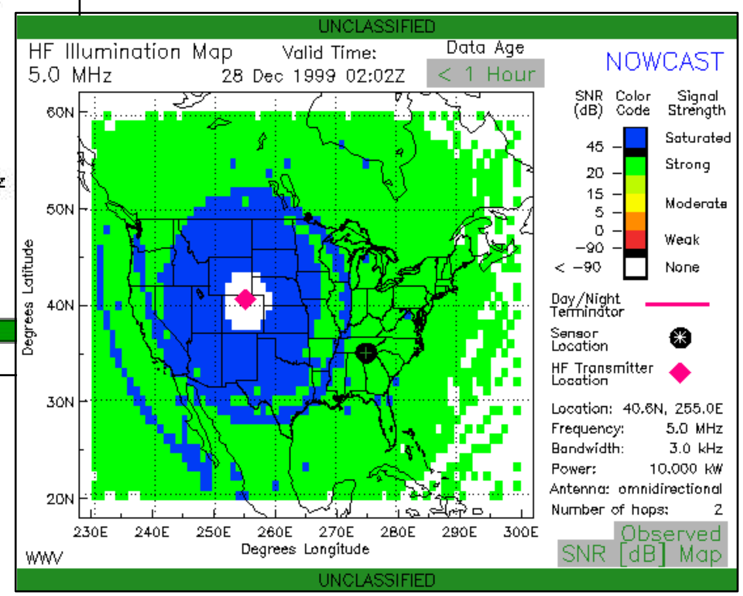
Global Theater Options



In-Theater Options



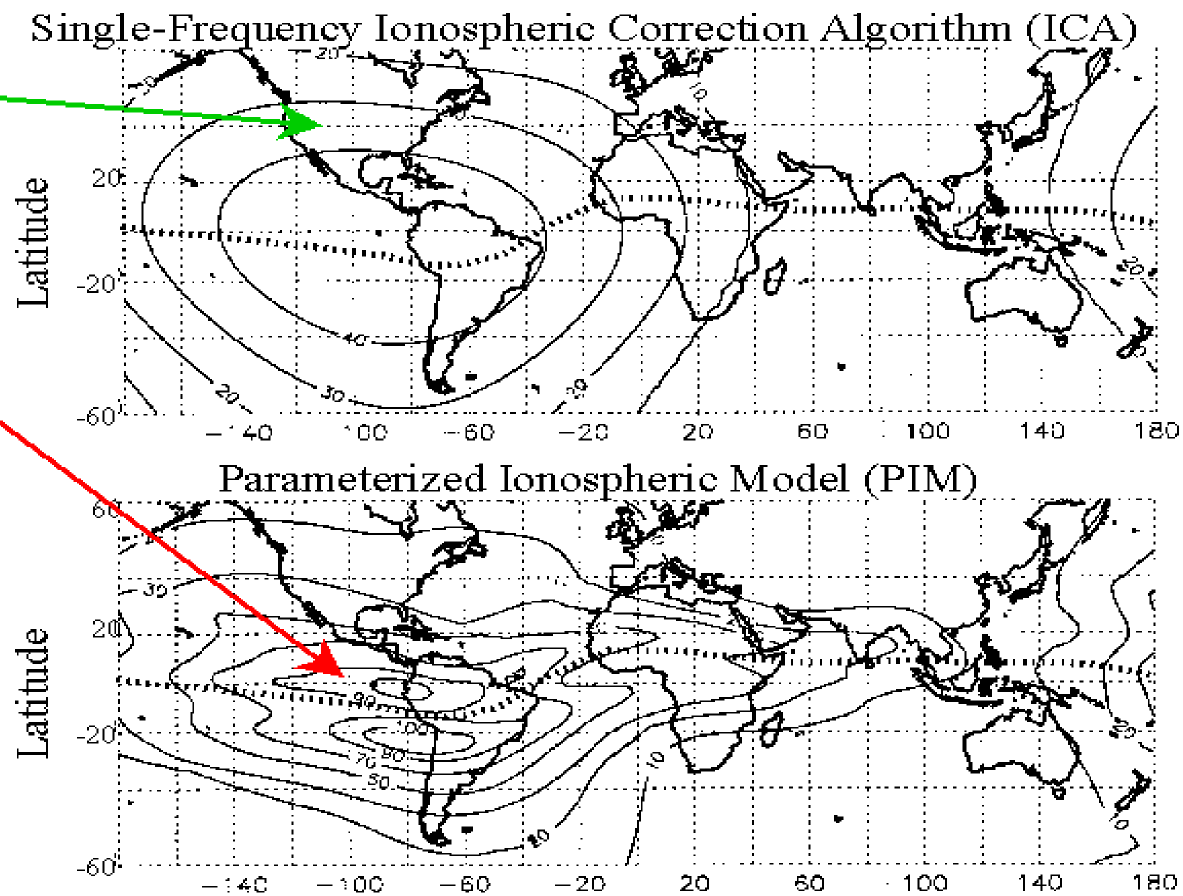
Selected Map Product



GPS Error

ICA Correction is Fairly Good Over CONUS, Where Ionosphere Varies Smoothly

ICA Correction is Poorer Near Magnetic Equator, Where Ionosphere Has Large Variations

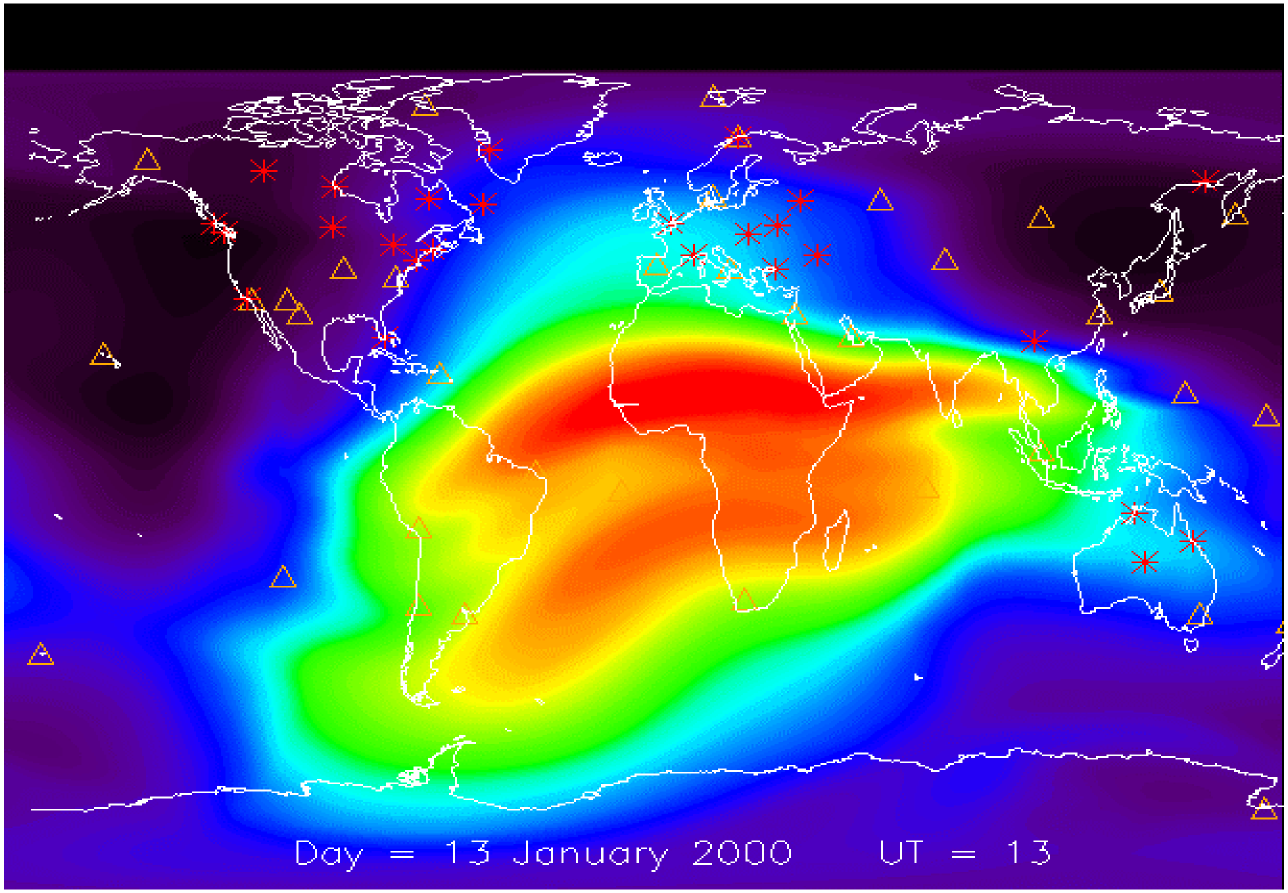


Ionospheric Correction Algorithm (ICA) within GPS, transmitted in Navigation Message, = f(Season, solar activity).

When no selective availability, Ne is the largest error source (~4m, vs total rms ~ 5 m) (Parkinson, 96)

PRISM VALIDATION
Significant Improvement over climatology

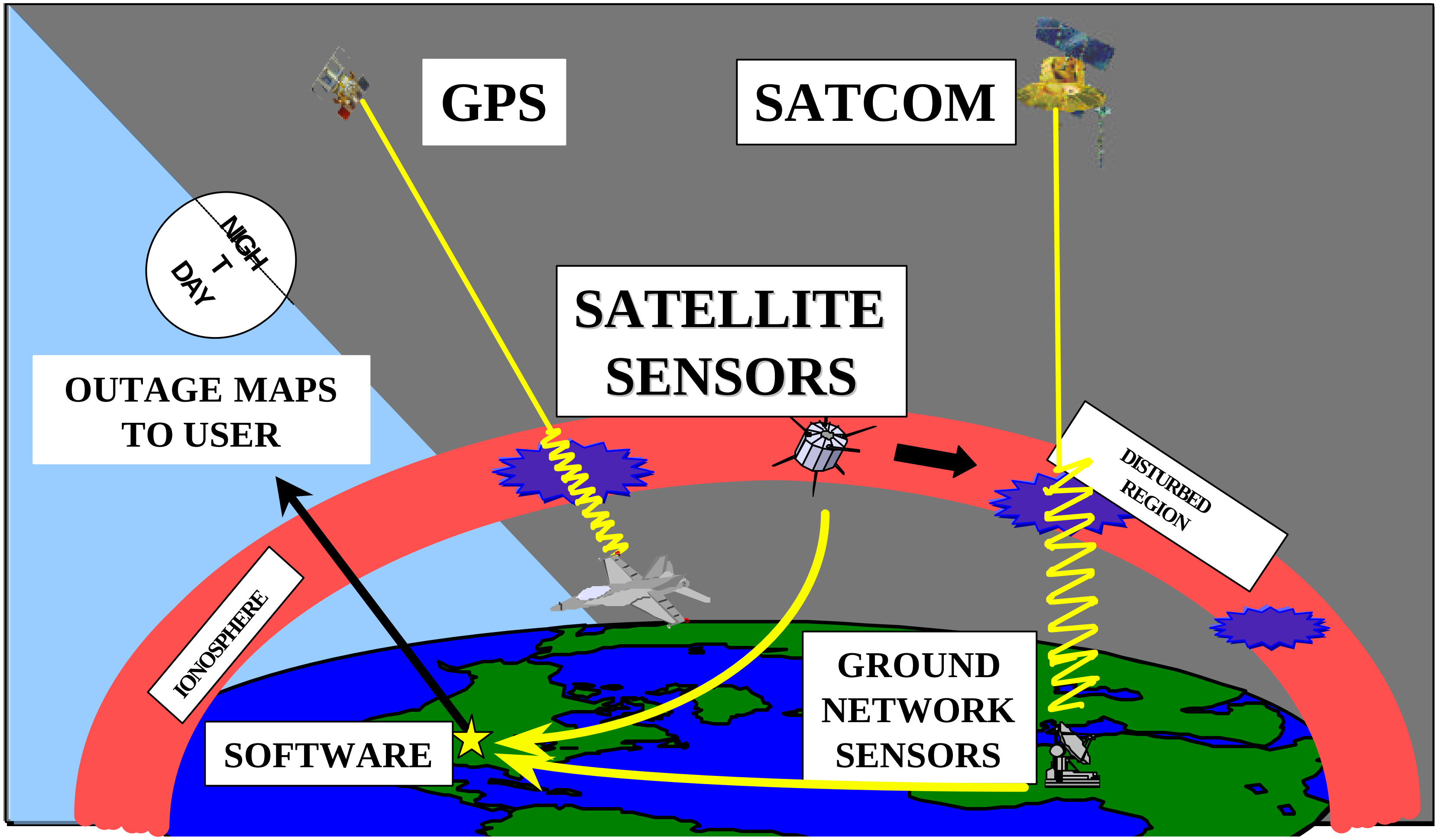
PRISM driven with 36 GPS receivers (triangles), rms error reduced by 42% at 24 ground truth stations (stars), compared to PIM with no real-time adjustment (Pulliam and Borer, 2001)



Implement Solution

Integrate Ground and Space systems – Ensure data transmitted within required t

Scintillation Outage Maps and EDPs are C/NOFS end products



Main Challenges – Conclusions --1

- Assimilate large and disparate data sets
  - Several groups making significant inroads
  - Within SpWx, Ionospheric applications might be the leaders in this field
- Long-term Forecast
  - Possibly the most difficult challenge
- Couple and link models together
  - Several groups have made significant inroads
  - Example: ionosphere/thermosphere/RT instability

Main Challenges – Conclusions --2

- **Make the right measurements -- Ground-based**
  - **operational systems, need to be reliable, & accurate, are expensive to maintain**
  - **Future solution might be to design and build multitude of cheap sensors**
- **Make the right measurements -- Space-based**
  - **New DMSP**
  - **C/NOFS**
  - **NPOESS**

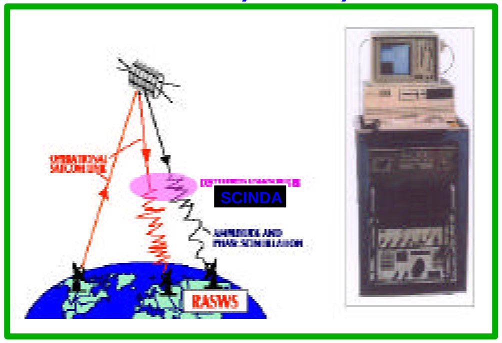
Main Challenges – Conclusions --3

- Establish how systems are affected—build products
  - Example of OpSEND
- Validate and benchmark models and products
  - PRISM validation
- Transition products / implement solutions
  - Rapid Prototype Center (Colorado Springs) for DoD
  - Ensure data are timely

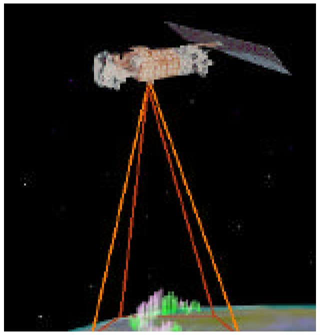
Conclusion

Applications to improve the performance of Nav, Com & Surv Systems through Real Time Global Monitoring, Specification and Forecast of Ionospheric Hazards

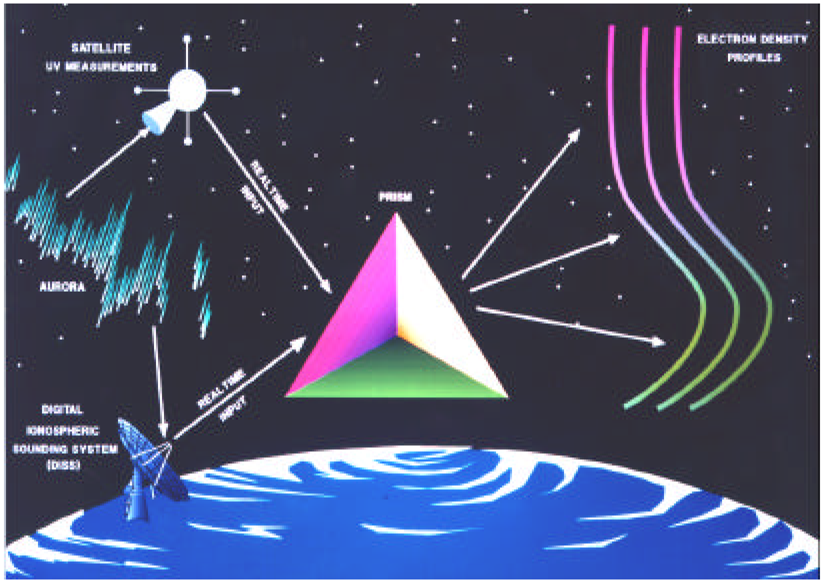
Ground-Based Sensors: DISS, IMS, etc.



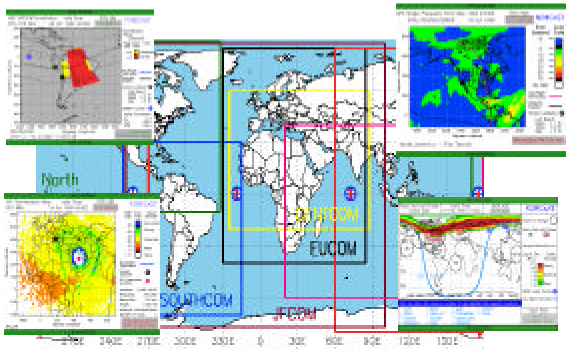
Space Sensors: DMSP, C/NOFS, etc.



Ionosphere Specification and Forecast Models

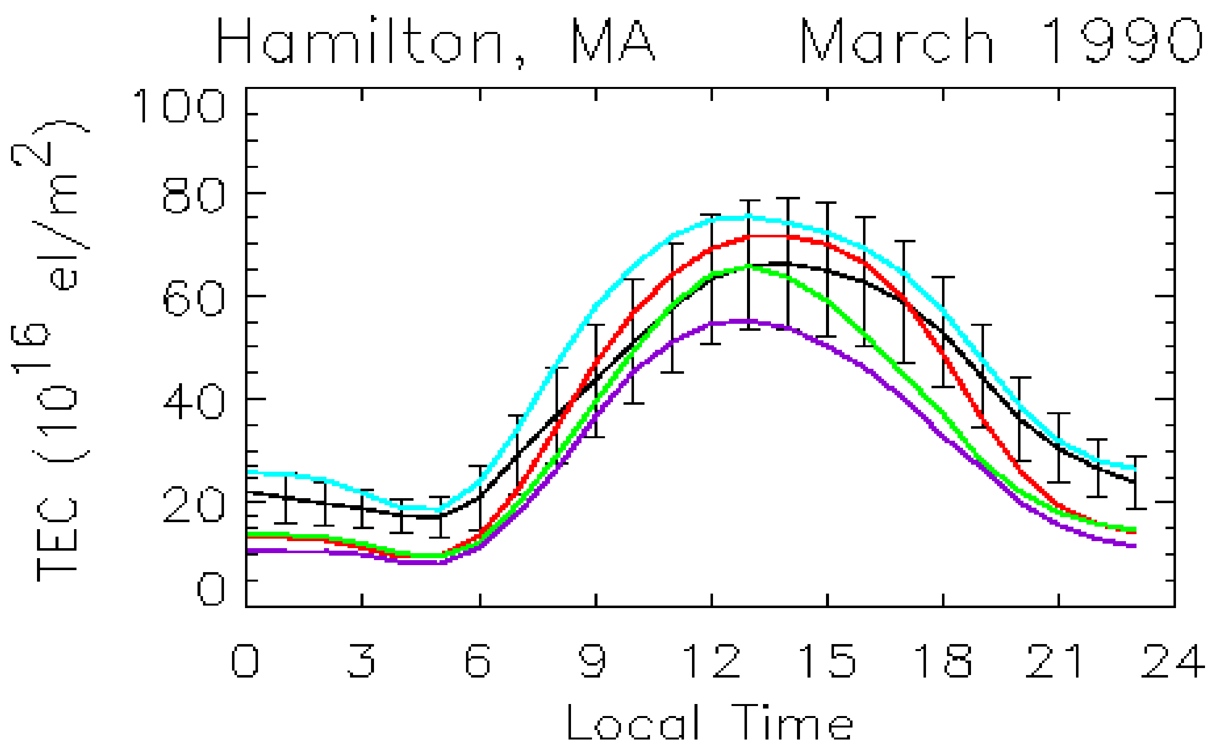


Ionospheric Impact Products



Validation and Metrics

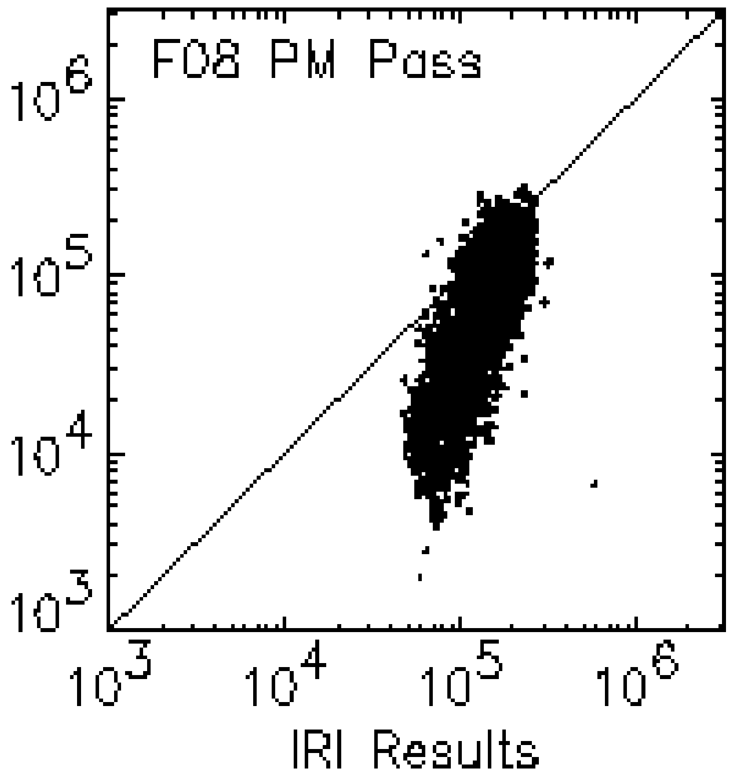
PIM comparison with other models

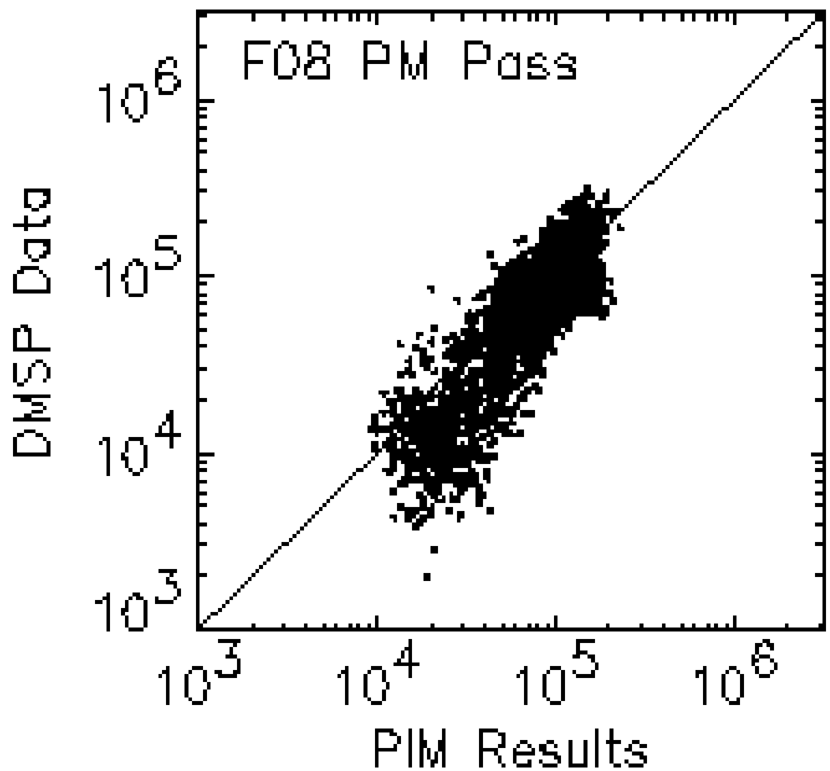


- **Comparison of TEC from data (black) and from PIM (red), IRI (blue), BENT (purple) and RIBG (green)** (Decker et al., 2000)
- **PIM performance comparable to other models**

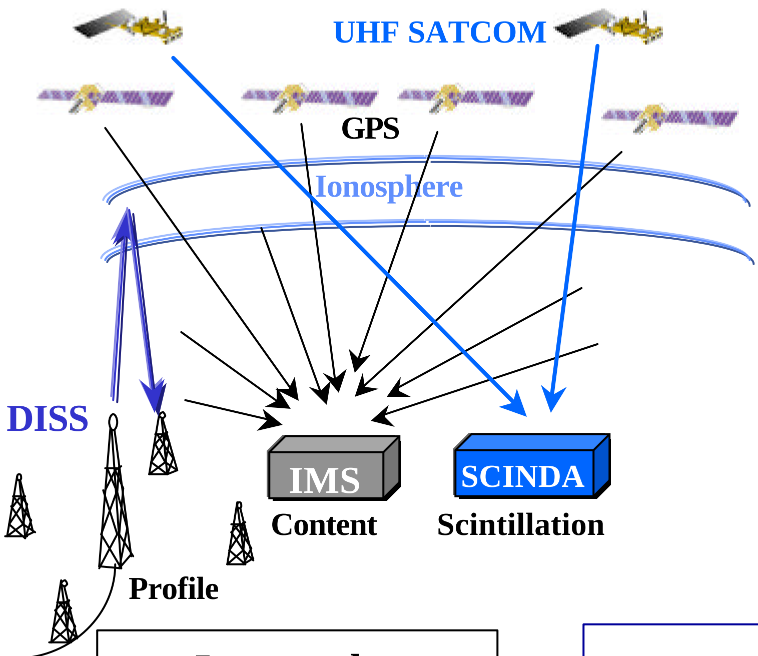
PIM & IRI -- comparison with DMSP data

- **Density at 840 Km altitude from DMSP versus IRI and PIM. (1991, one year average, MLAT=50 degrees, LT=18)**

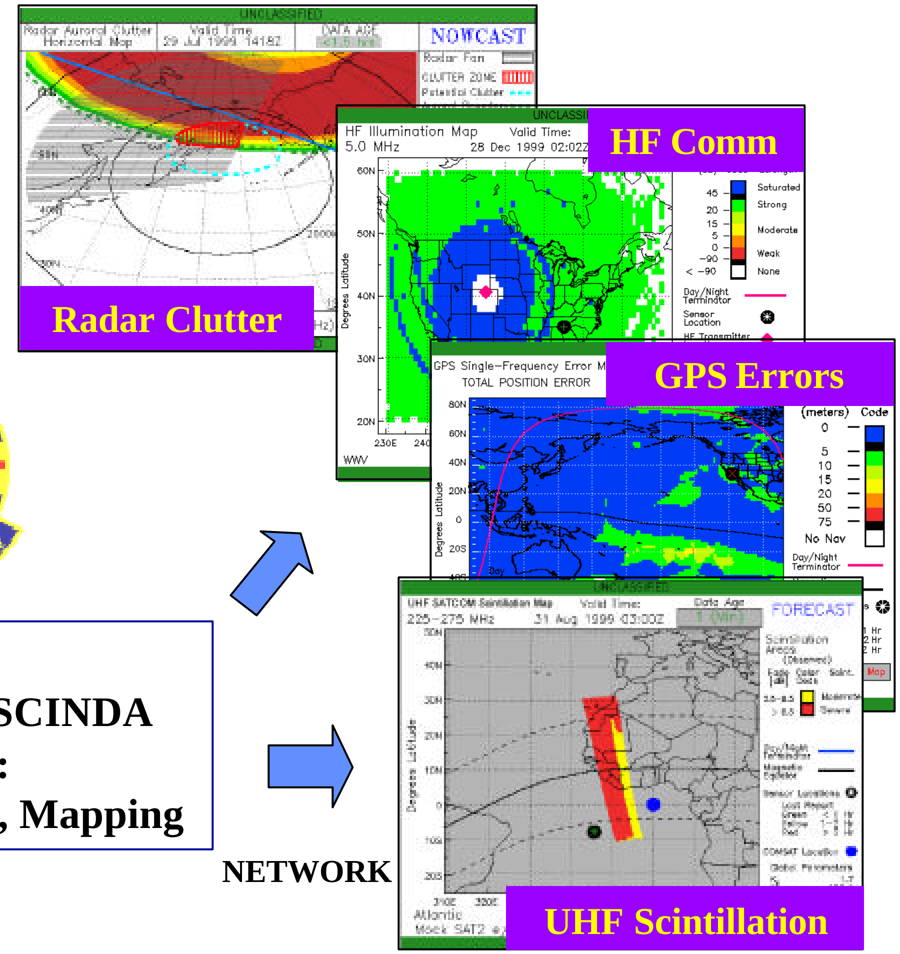




OpSEND System Details



DMSP



Ionosondes
GPS receivers
Scintillation Sensor

Networks: GPS & Magnetometer

Models:
Auroral, PRISM, SCINDA
Algorithms:
HF Raytrace, GPS, Mapping

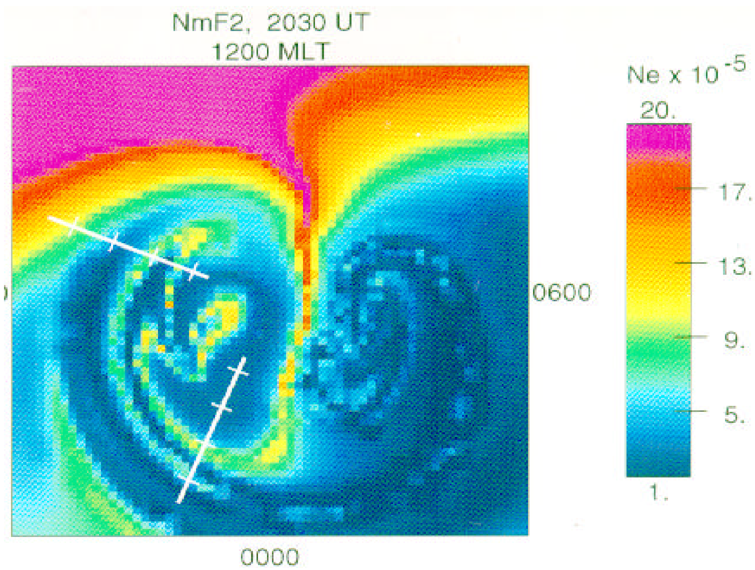
NETWORK

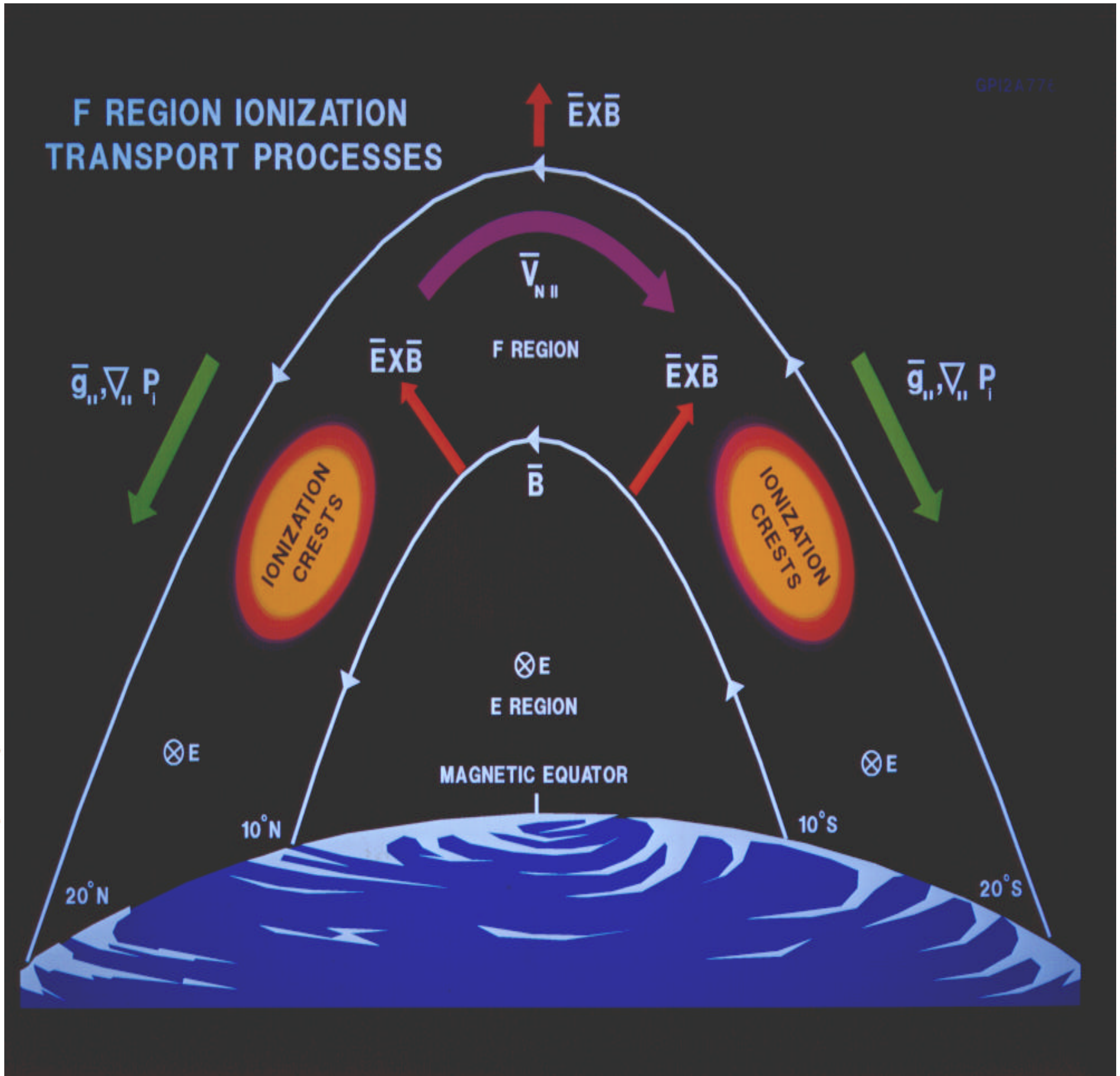
Sensors	Models & Product Drivers	User Products
Theater	Operational center	Global Users

PIM

Parameterized Ionospheric Model (PIM):

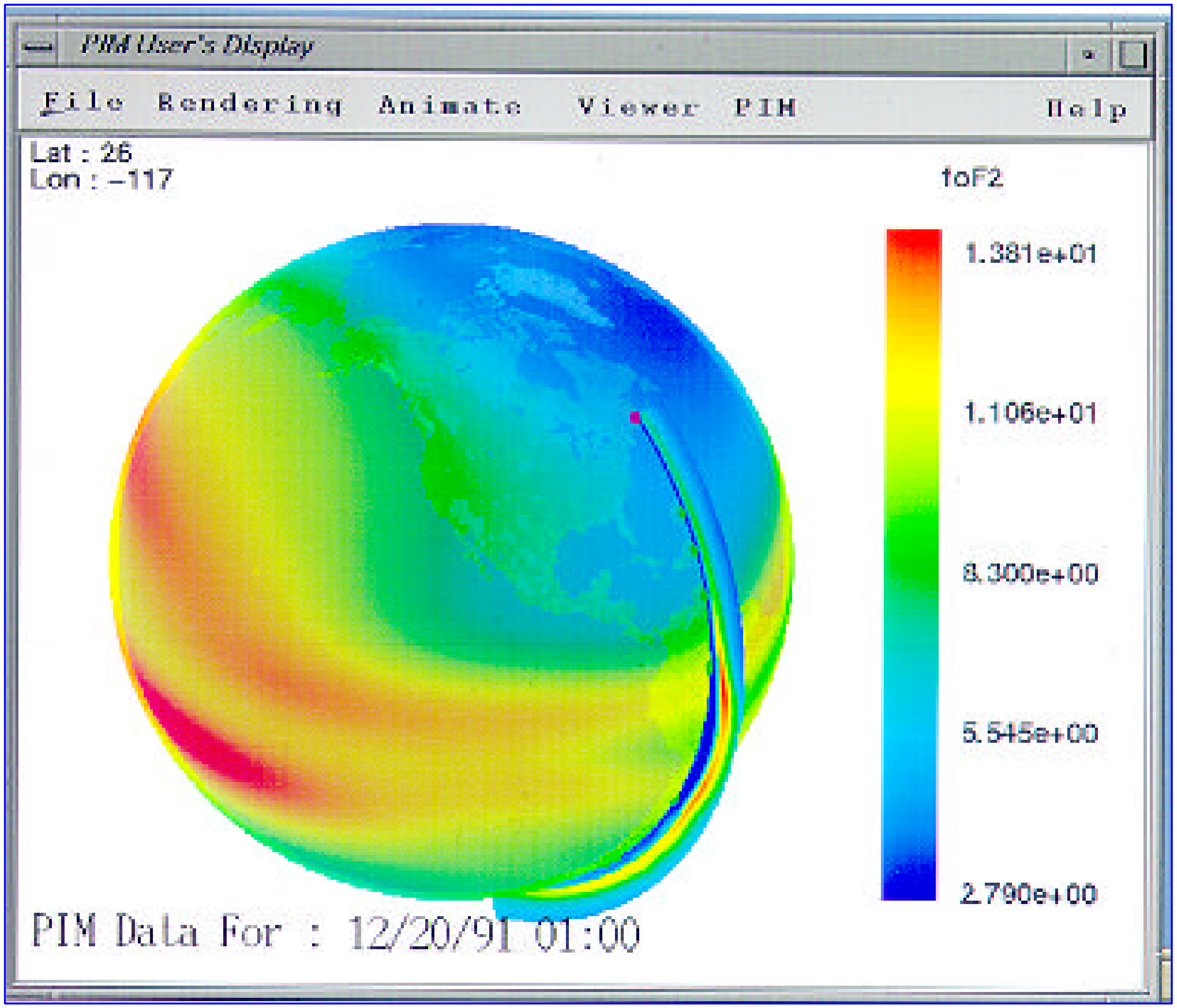
- **Physical model based on: Schunk 88, Anderson 73, Jasperse 82**
- **Results parameterized**





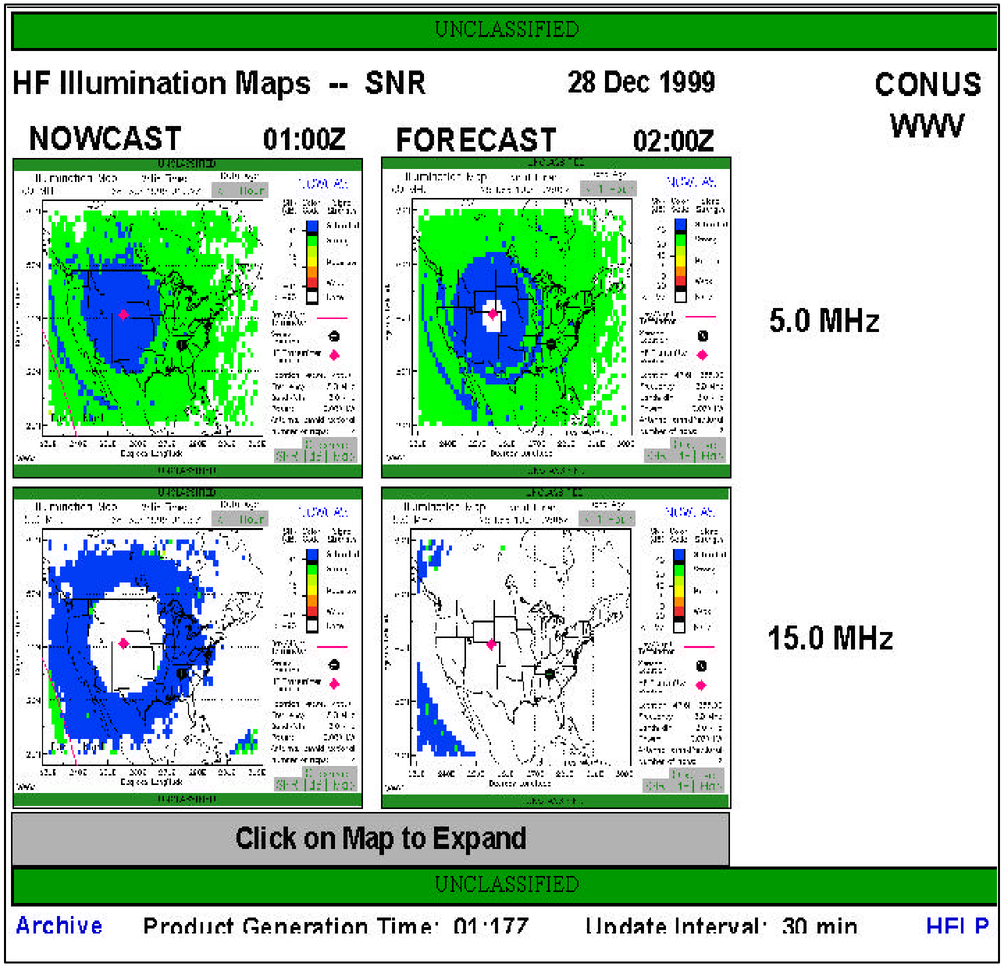
PIM

- Input includes: time, location, Kp, F10.7, IMF
- Can be normalized to match URSI F-region Model
- Output includes:
  - TEC
  - Profiles
  - E or F region Max
  - f_0 F2
- Used for climatology, long-term forecast, PRISM initialization



OpSEND HF Illumination Map

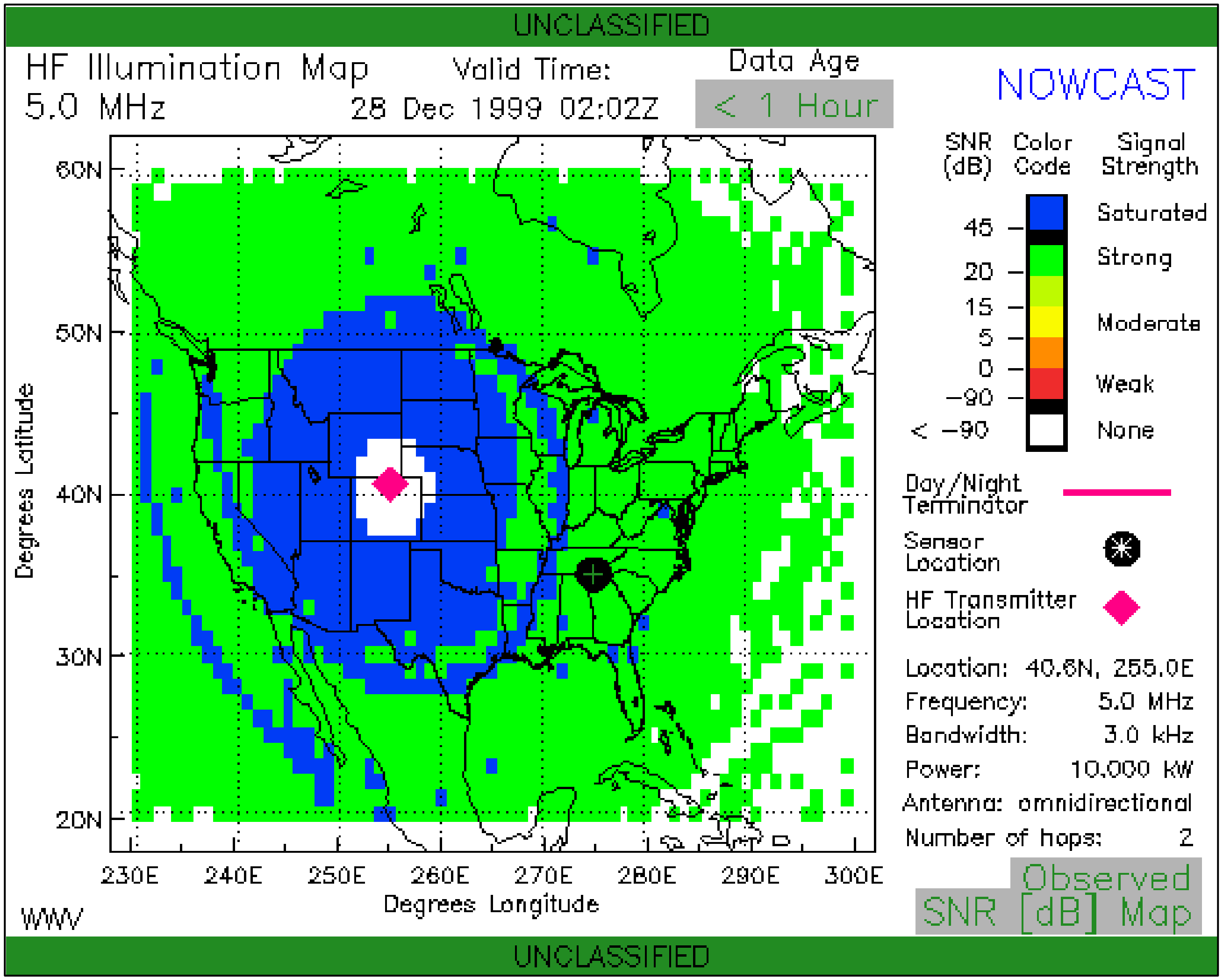
- **Display amount of HF radio energy that reaches every part of a chosen theater from a specified transmitter**
- **Includes multiple hop**
- **User selects frequency, and either nowcast or forecast**



Level-2 Example

OpSEND HF Illumination Map

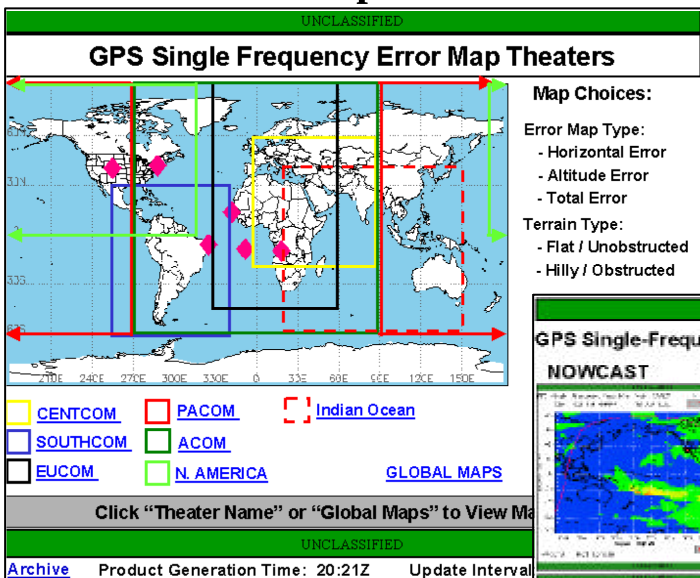
Level 3 -- Strength of HF illumination for 5 MHz, Boulder Transmitter



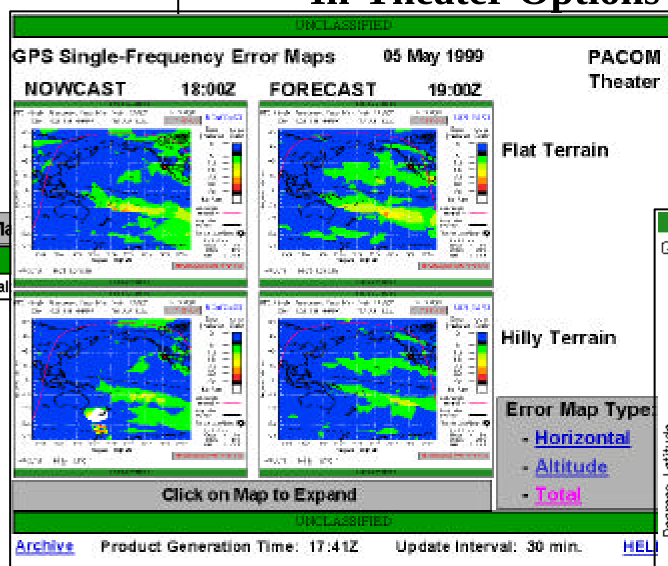
GPS Single-Frequency Error Map

3 - Level Web Page

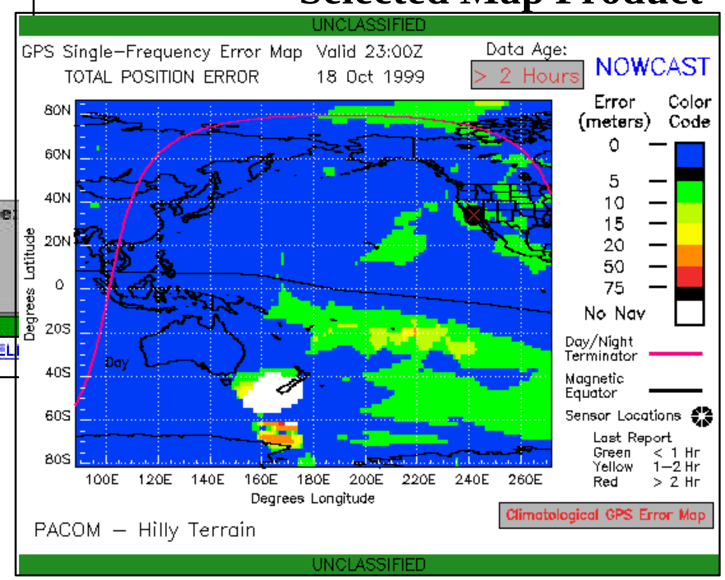
Global Theater Options



In-Theater Options



Selected Map Product



GPS Single-Frequency Error Map

Level 1: Either global or specific map can be selected

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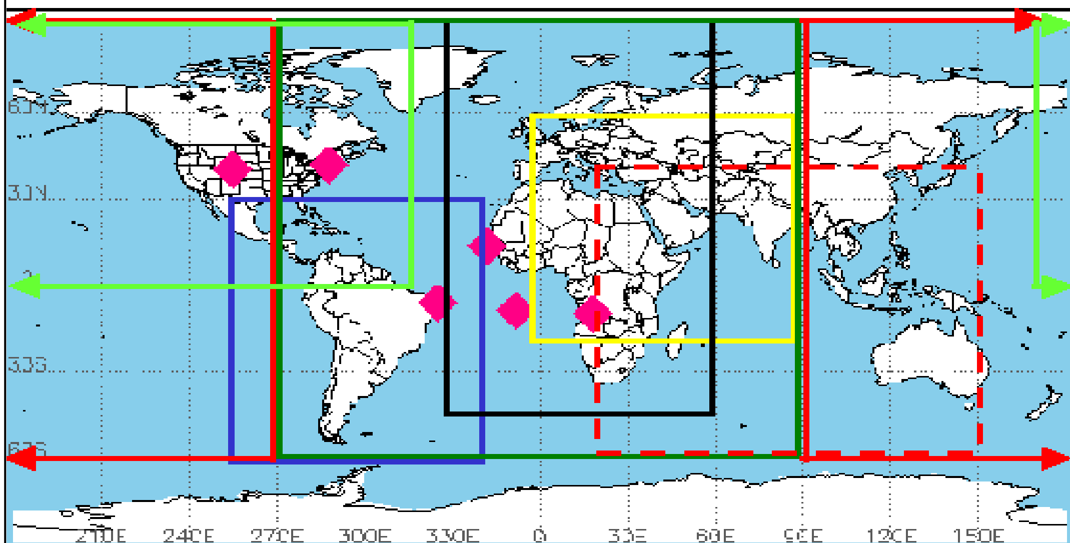
GPS Single Frequency Error Map Theaters



Map Choices:

Error Map Type:
- Horizontal Error
- Altitude Error
- Total Error

Terrain Type:
- Flat / Unobstructed
- Hilly / Obstructed

CENTCOM | PACOM | Indian Ocean
SOUTHCOM | ACOM
EUCOM | N. AMERICA | GLOBAL MAPS

Click "Theater Name" or "Global Maps" to View Map Choices

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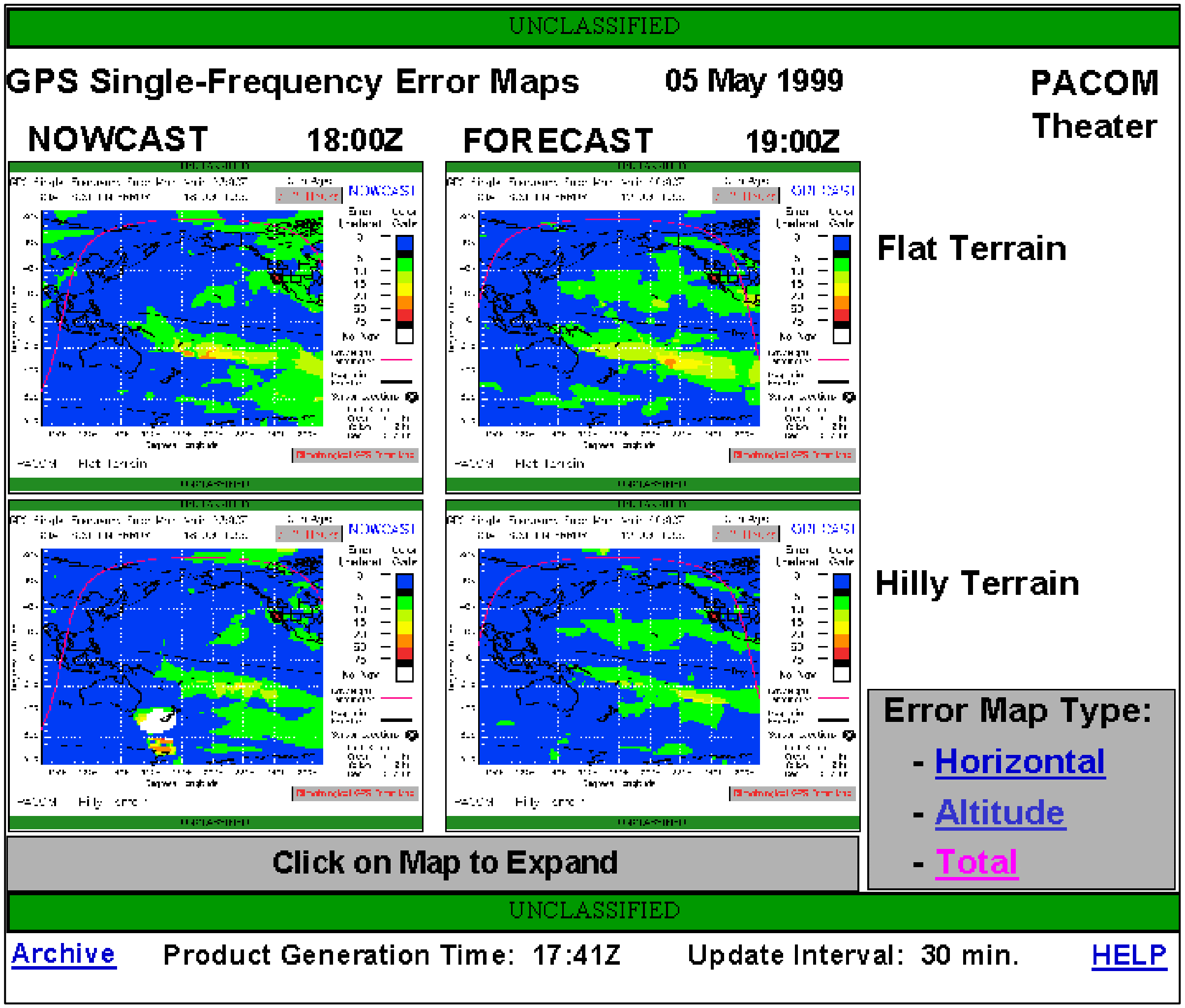
Archive   Product Generation Time: 20:21Z   Update Interval: 30 min.   HELP

GPS Single-Frequency Error Map

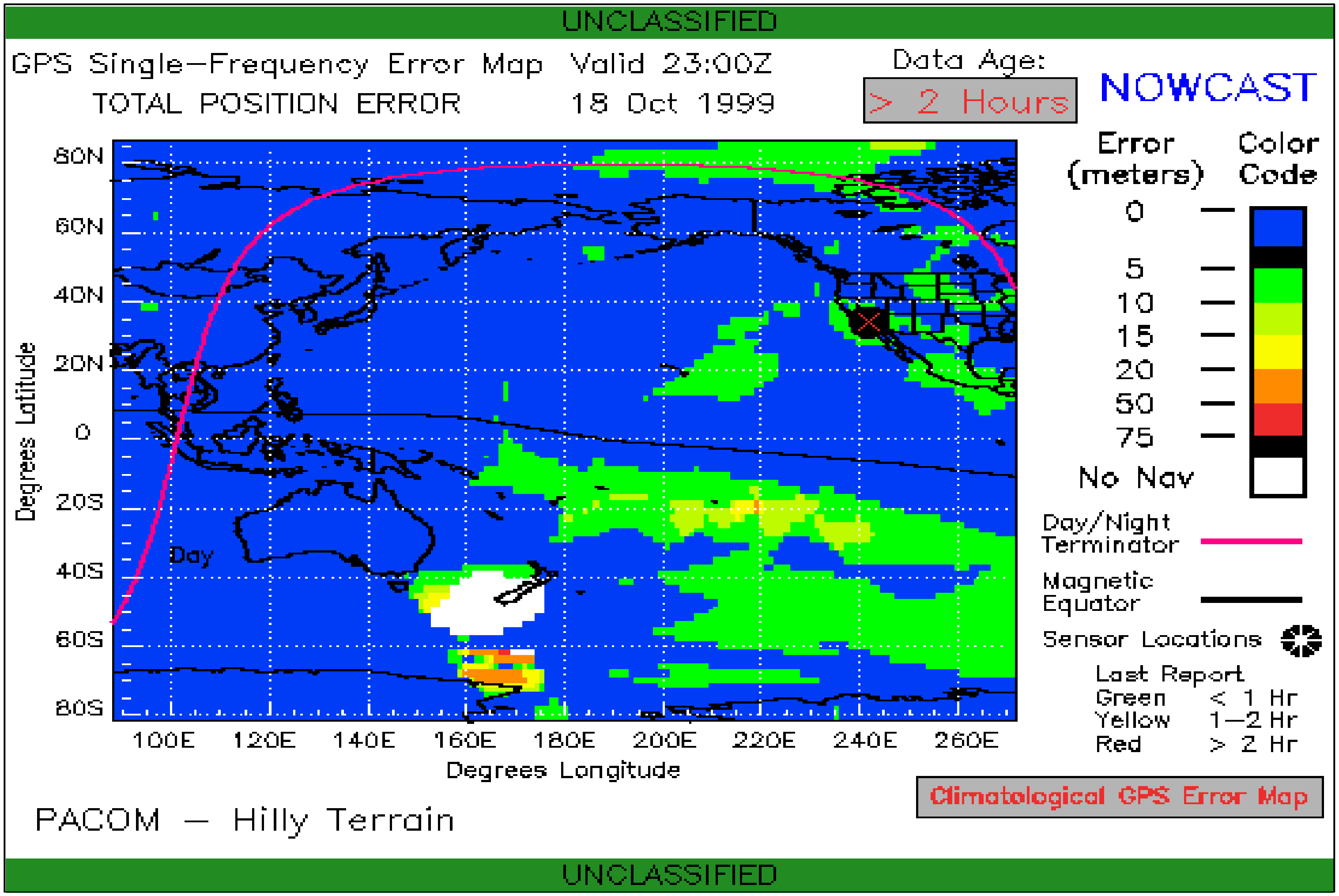
Level-2 Selections:

- Nowcast or 1-hr forecast
- Flat or "hilly" terrain
- Type of error estimate
  - horizontal error
  - altitude error
  - total position error



GPS Single-Frequency Error Map

Level 3: Example of total position error (m) for hilly terrain (low elevation satellites obstructed)



Space Weather Future Directions

Models/Products	Sensors/Data
Climatology - Statistical/empirical	**Regional Coverage** -Several local sensors
Local Specification **-** Proxy-driven climatology - Locally physics-based - Qualitative forecasts	We are here **Global Coverage** - Many local sensors - Local remote sensing - Long time data bases
Global Specification - Data assimilation - Cross-domain coupling - Solar-cycle climatologies	
Forecast - Globally physics-based - Quantitative	**High Resolution Global Coverage** - Microsat constellations - Global remote sensing

National/International Effort

Research Partners

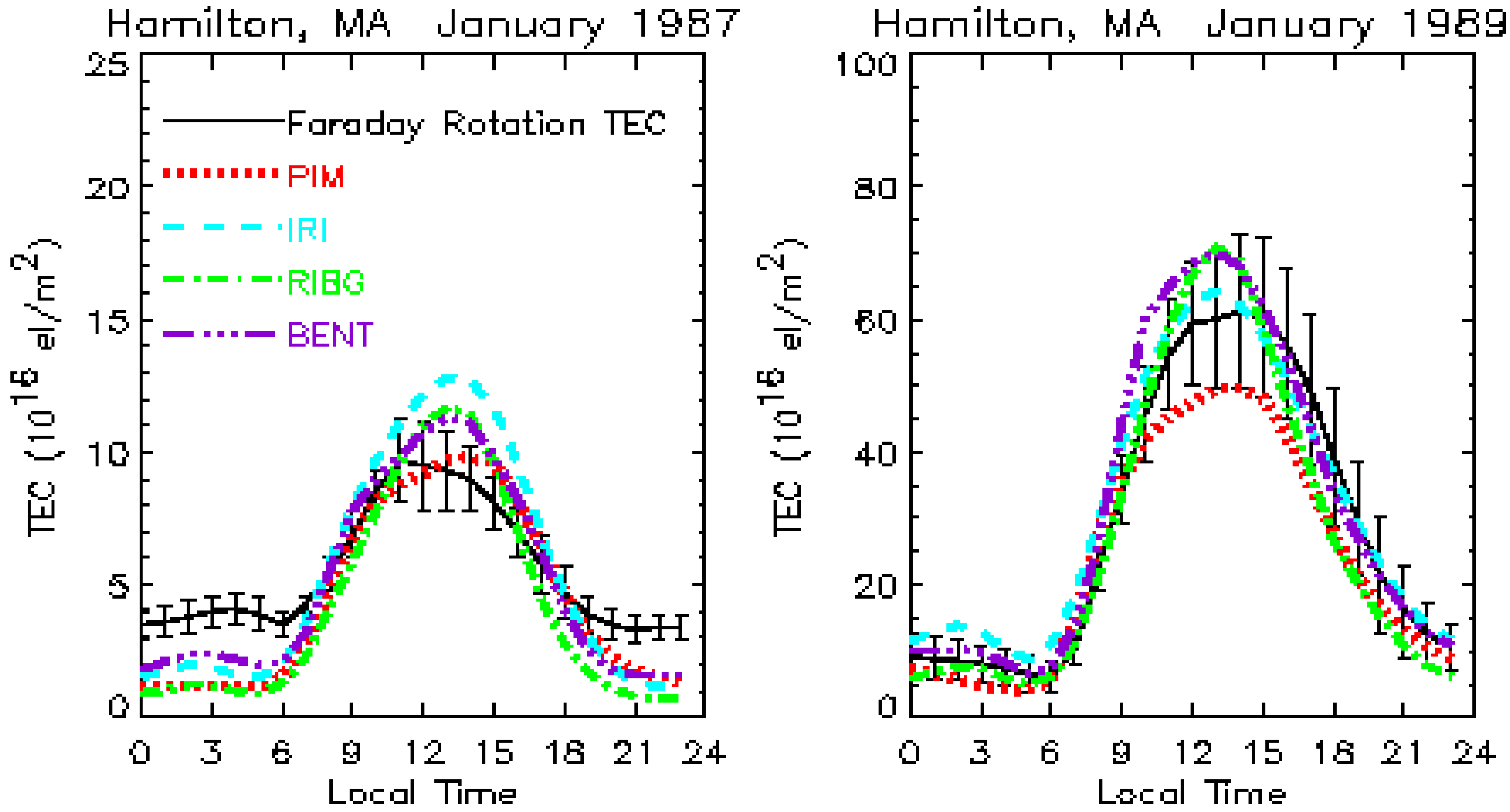
- NASA Living with a Star
- National and international community
- NRL, APL, JPL, LANL, Aerospace, NOAA, etc

Transition Partners

- DoD Space Weather Operations and Rapid Prototype centers
- NOAA Space Env. Center
- DoD
- Industry

PIM comparison with other models

- **Comparison of TEC from data (black) and from PIM (red), IRI (blue), BENT (purple) and RIBG (green)** (Decker et al., 2000)
- **PIM performance comparable to other models**

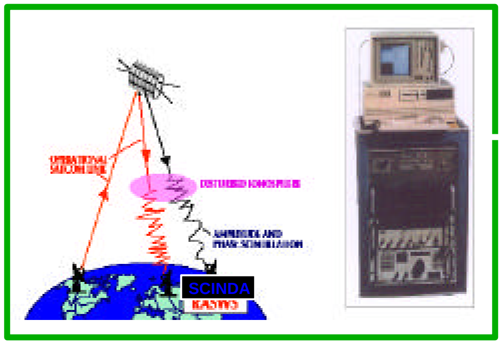


TEC comparison for low and high F10.7

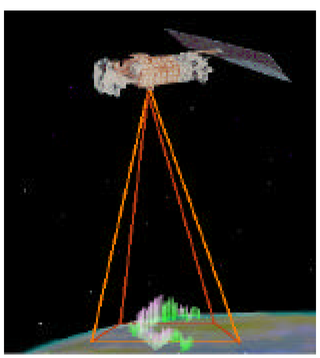
Conclusion

Improve the Performance of Nav and Com Systems Through Real Time Global Monitoring, Specification and Forecast of Ionospheric Hazards

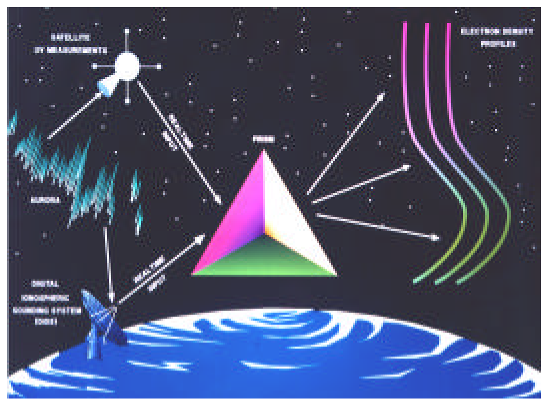
Ground-Based Sensors: DISS, IMS, SCINDA, etc.

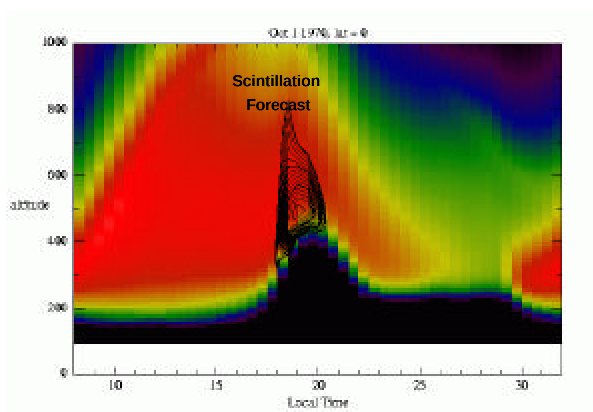


Space Sensors: DMSP, CNOFS, etc.

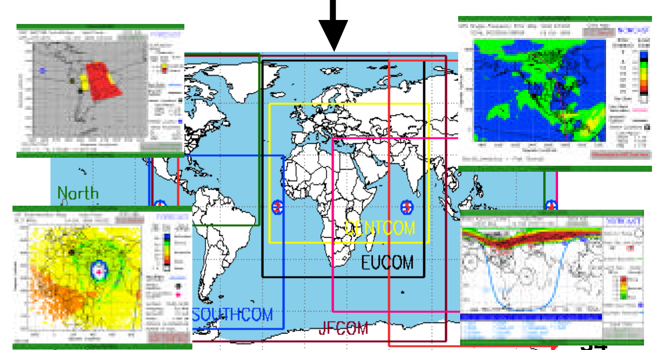


Ionosphere Specification and Forecast Models





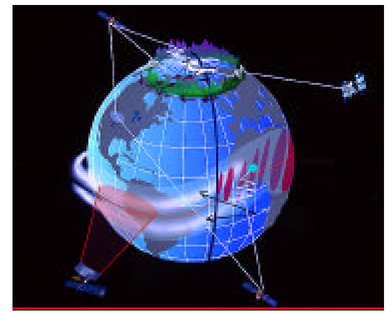
Ionospheric Impact Products



Technical Challenges

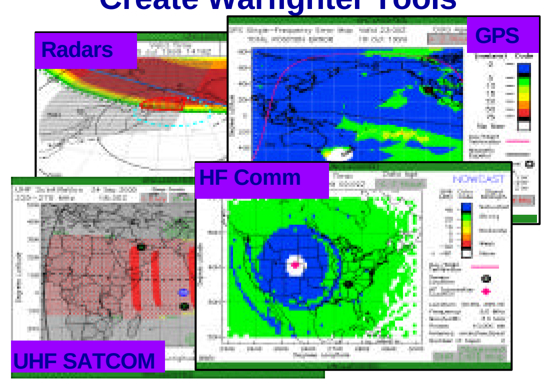
- Understanding the Basic Physics of a Complex, Dynamic Environment
- Developing Optimal Sensor Systems to Monitor Globally
- Integrating New Knowledge Into Operational Tools / Models / Products

Understand Environment



Measure & Model

Create Warfighter Tools



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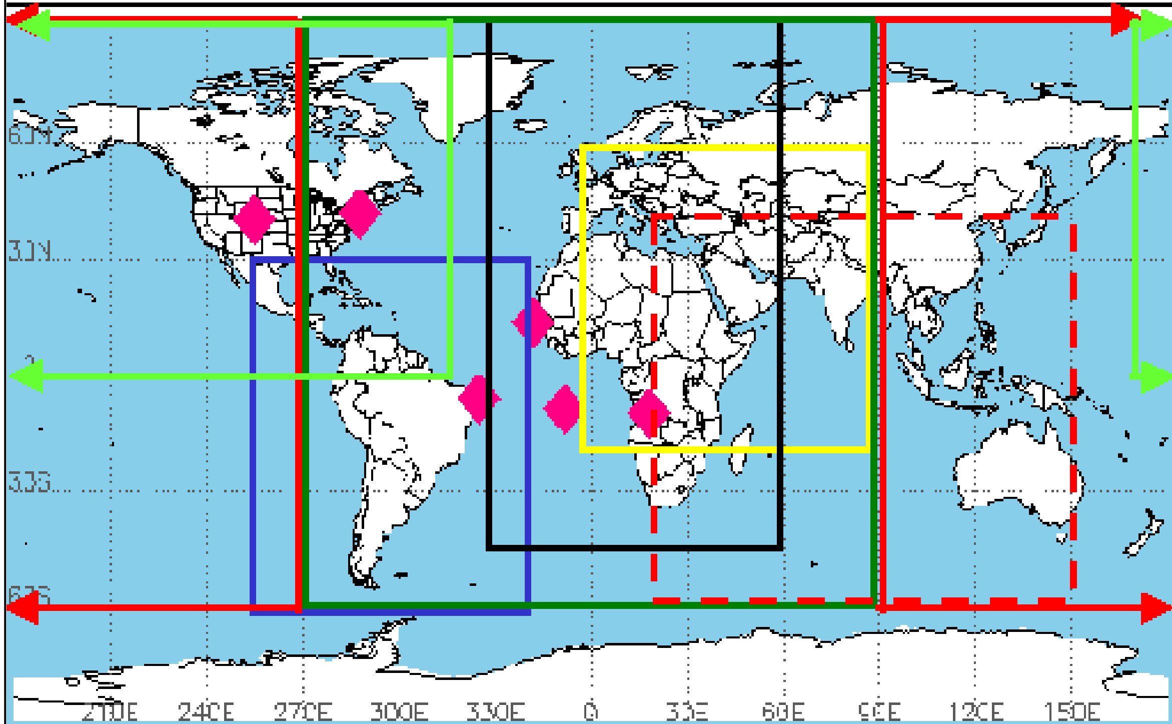
GPS Single Frequency Error Map Theaters



Map Choices:

Error Map Type:
- Horizontal Error
- Altitude Error
- Total Error

Terrain Type:
- Flat / Unobstructed
- Hilly / Obstructed

CENTCOM
SOUTHCOM
EUCOM
PACOM
ACOM
N. AMERICA
Indian Ocean
GLOBAL MAPS

Click "Theater Name" or "Global Maps" to View Map Choices

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Archive Product Generation Time: 20:21Z Update Interval: 30 min. HELP

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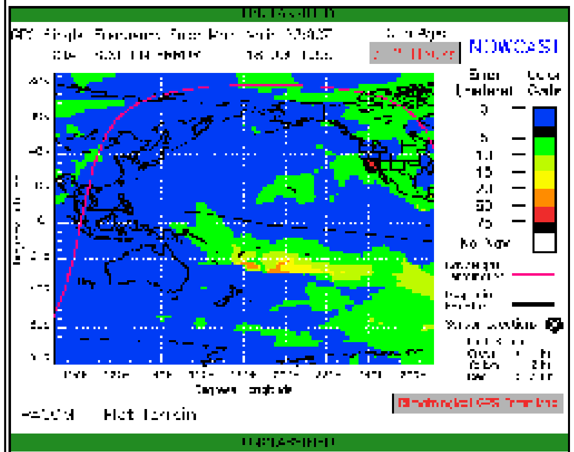
GPS Single-Frequency Error Maps

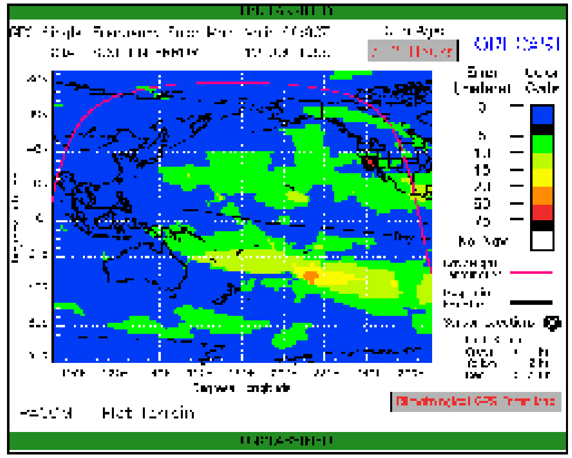
05 May 1999

PACOM Theater

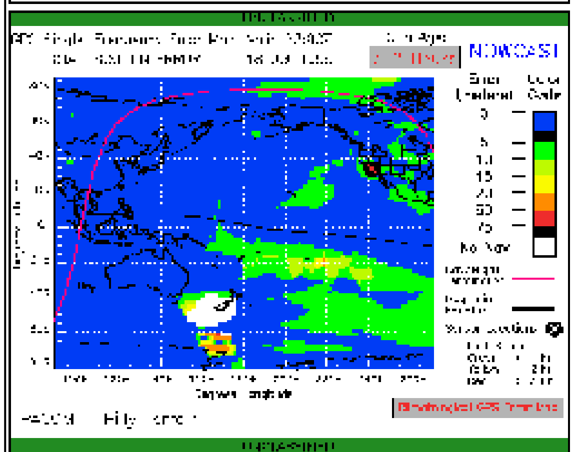
NOWCAST 18:00Z

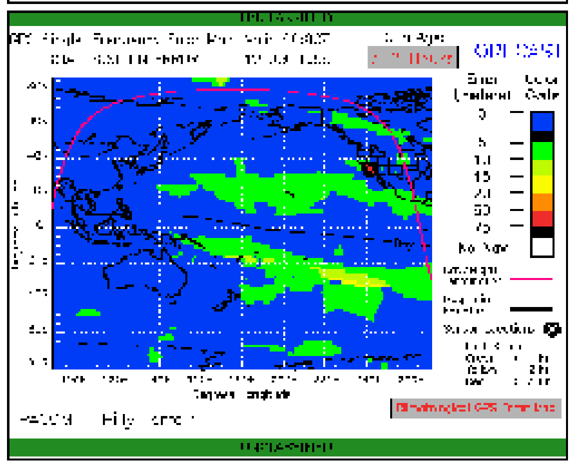
FORECAST 19:00Z





Flat Terrain





Hilly Terrain

Click on Map to Expand

Error Map Type:

- Horizontal
- Altitude
- Total

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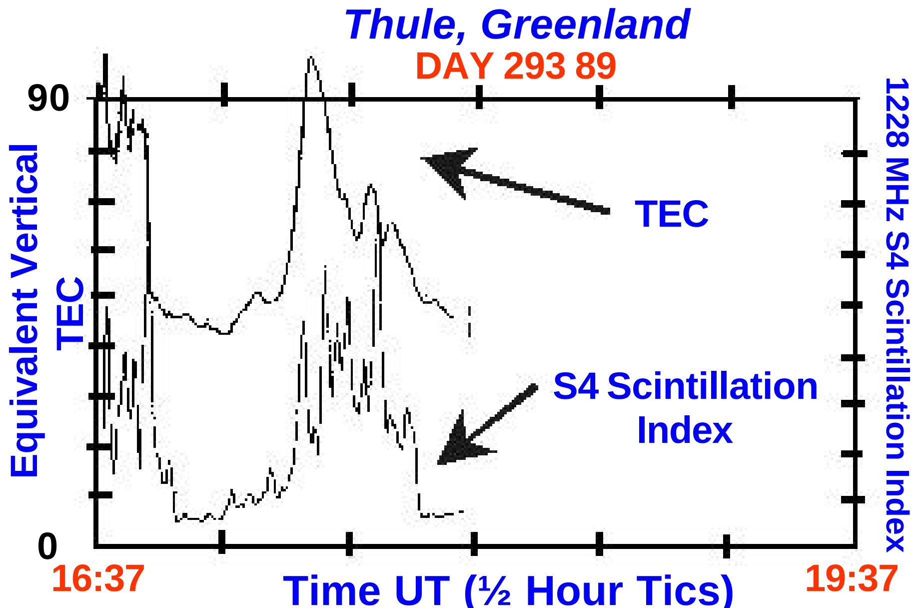
Archive   Product Generation Time: 17:41Z   Update Interval: 30 min.   HELP

FY99-00 Accomplishment
Mapping Polar Cap Plasma Patches*

Problem

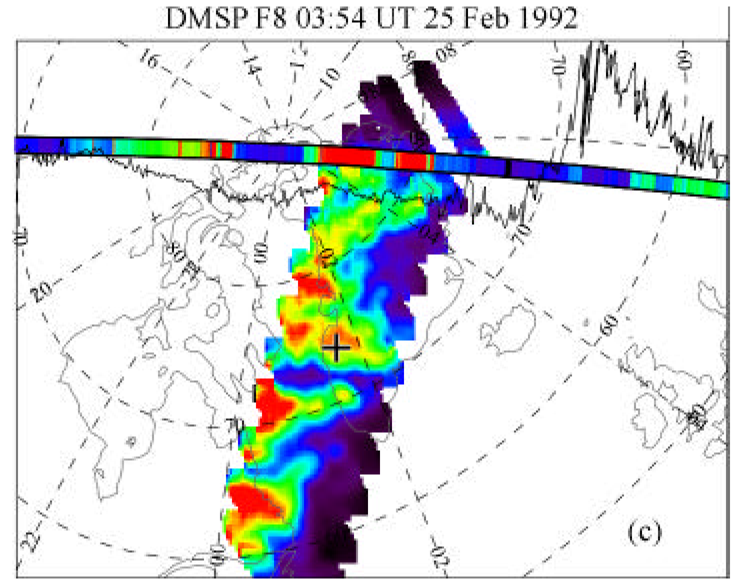
Polar Cap Plasma Densities Vary on Time Scales of Minutes; High Density Regions Associated with Scintillation



Bishop, et al.

Accomplishment

Successfully Demonstrated Capability to Map Polar Cap Structures Regionally Based on Local Observations



* AFOSR Star Team

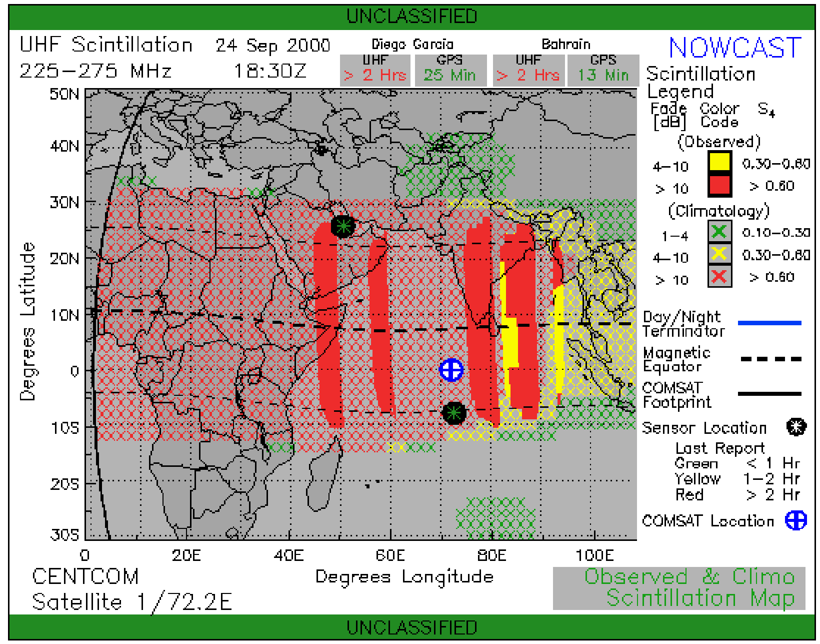
Impact

New Capability for Nowcasting Disruptions to High Latitude Radars for National Missile Defense

TECHNOLOGY TRANSITION
SCINDA Deployed to CENTCOM

Scintillation Network Decision Aid

- **Data-Driven Regional Scintillation Nowcasts**
- **Products Briefed Daily to 5th Fleet Operations**
- **Additional Support Now Requested in CENTCOM and PACOM**

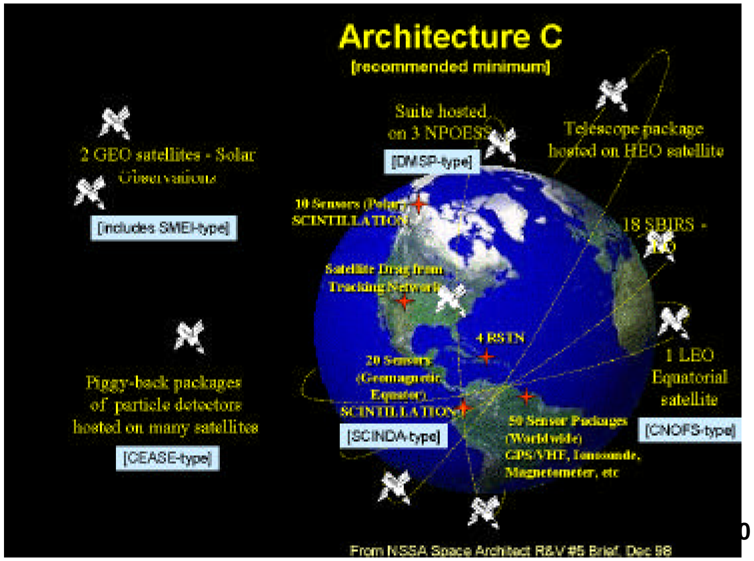


<u>Impact</u>

Situational Awareness for UHF SATCOM Users and Mission Planners in CENTCOM

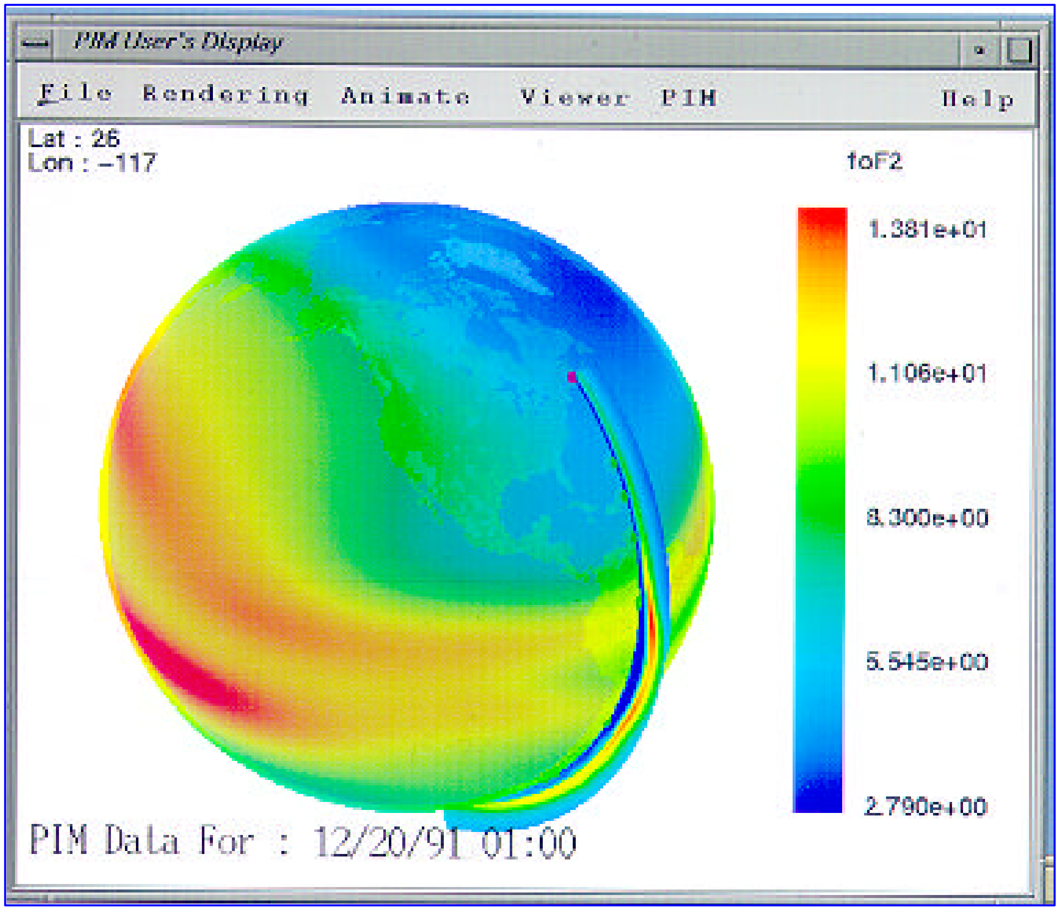
CONCLUSIONS

- Innovative Comprehensive Approach
  - Strong Integrated Program on Sensors, Models, Products
  - Provides Flexible Range of Technologies for Tradeoffs
  - Combined Efforts of Two AFOSR STAR Teams
- Program Focused on Key Space Weather Hazards
  - Modern Sensor Technology
  - State-of-the-Art Physics-Based Models
  - Tailored Warfighter Products
- Clear Vision for the Future
  - Know the User Needs
  - Have Clear Goals
  - Roadmaps for the Future



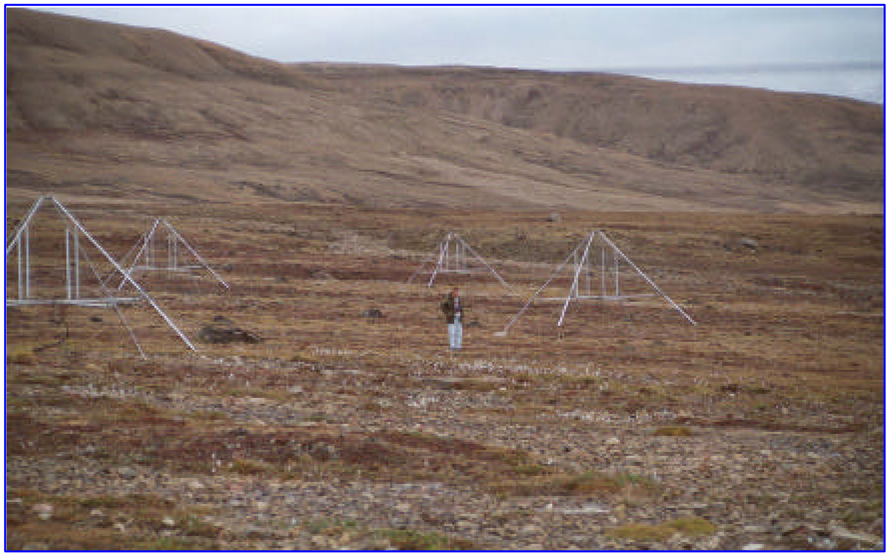
PIM

- **Parameterized Ionospheric Model**
  - **Physics-based model based on Schunk 88, Anderson 73, Jasperse 82, Decker**
  - **Parameterized**
  - **Can be normalized to match URSI F-region Model**
  - **Outputs include:**
    - **TEC**
    - **Profiles**
    - **E or F region Max**
    - **fo F2**
- **Used for climatology, long-term forecast, PRISM initialization**



PRISM

- Parameterized Real time Ionosphere Model
- Ingested data from:
  - Ionosondes
  - GPS receivers
  - DMSP
- Other Input include: indices, Kp, F10.7, IMF

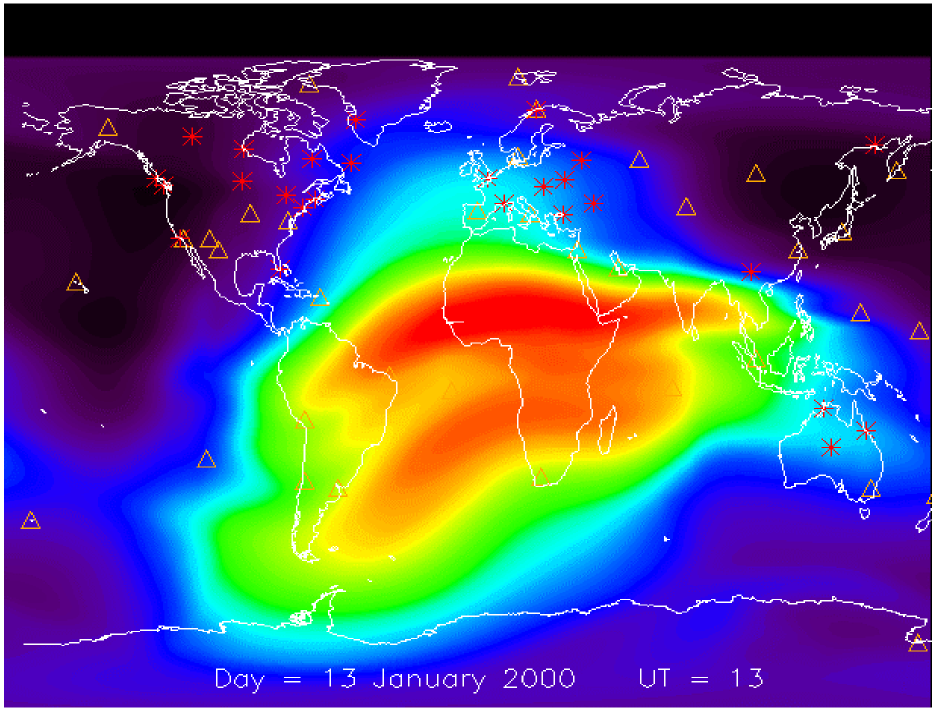


OpSEND Single-Frequency GPS Error Map

- **GPS receivers have a simple built-in ionosphere model,**

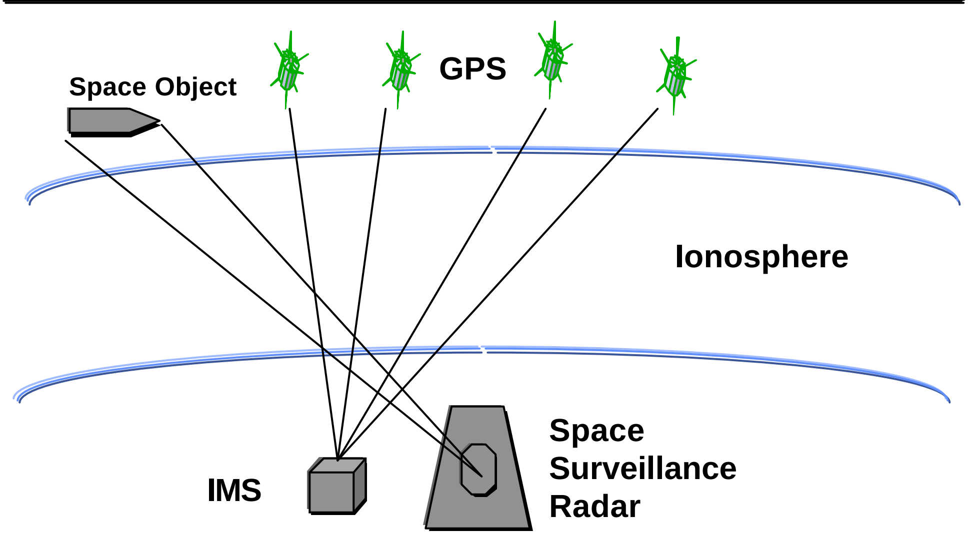
Future Directions

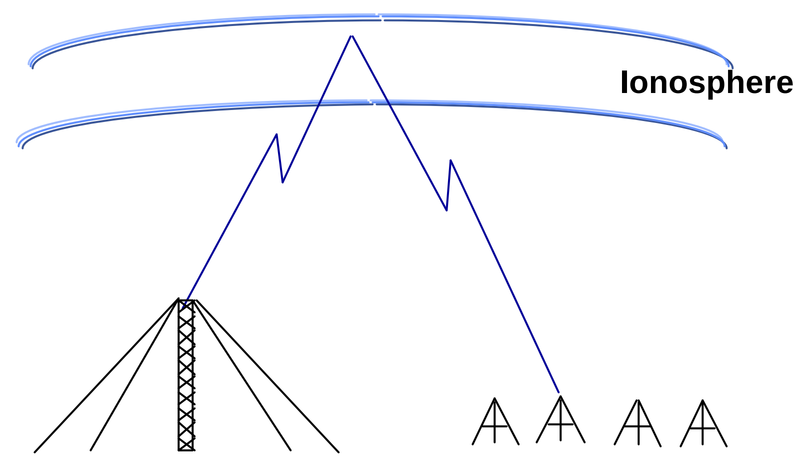
- **Specification and Forecast Assimilative Models**
- **Improved Products**
  - **Scientific and Operational Validation**



PRISM

- **Parameterized Real time Ionosphere Model (PRISM)**
- **Input include:**
  indices, Kp, F10.7, IMF
- **Assimilates realtime from:**
  - **GPS receivers**
  - **Ionosondes**
  - **DMSP**





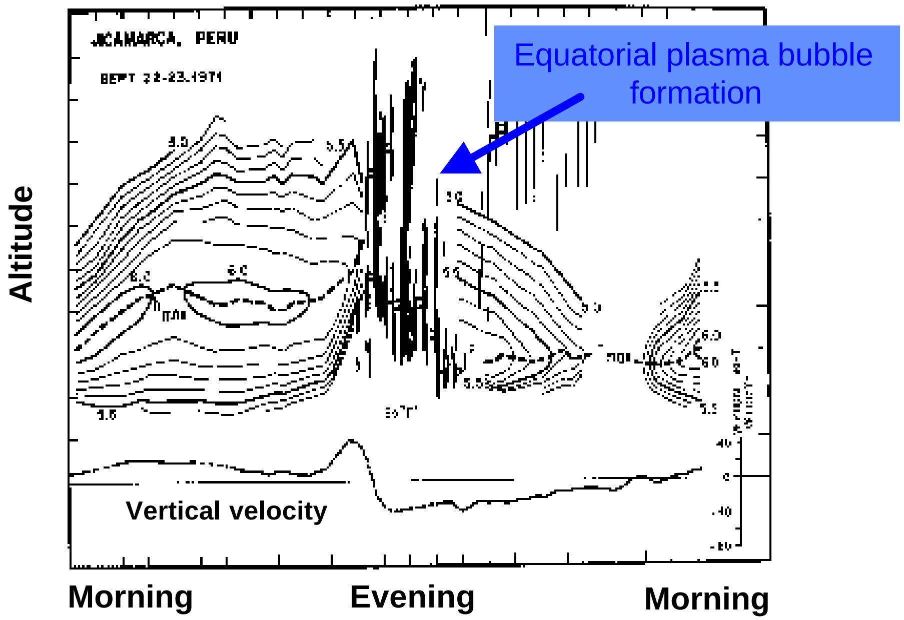
Basic Research

Ionospheric Instability Forecasts

<u>Problem</u>

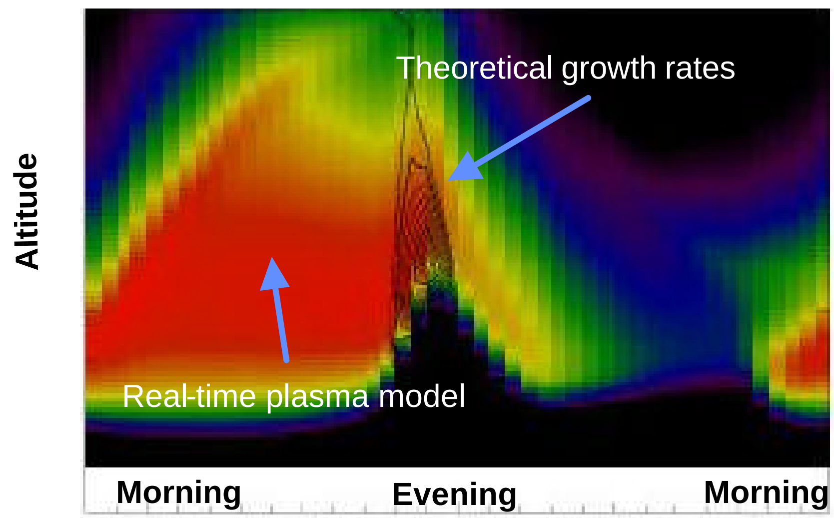
Ionospheric variability makes it difficult to predict occurrence of scintillations

Jicamarca Radar Plasma Density Scan



<u>Solution</u>

Identified key information for predicting ionospheric plasma instability - assimilated it into real-time model



<u>Impact</u>

Better prediction of the onset of scintillation conditions – essential for C/NOFS

C/NOFS Instruments

Instrument	Name	Measured Parameters	PI Organization
PLP	Planar Langmuir Probe	-Ion Density -Power Spectral Densities	AFRL (D. Hunton)
IVM	Ion Velocity Meter	-Vector Ion Drift Velocities	Univ. Texas, Dallas (R. Heelis)
NWM	Neutral Wind Meter	-Vector Neutral Wind Velocities	Univ. Texas, Dallas (G. Earle)
VEFI	Vector Electric Field Instrument	-Vector DC & AC Electric Fields	NASA Goddard (R. Pfaff)
CERTO	Coherent Electromagnetic Radio Tomography	-Space-to-Ground Scintillations -Ne Reconstruction	NRL (P. Bernhardt)
CORISS	C/NOFS Occultation Receiver for Ionospheric Sensing and Specification	-GPS Occultations -Line-of-Sight Ne -Space-to-space Scintillation	Aerospace (P. Straus)